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REPORT R-144

THE DEMAND FOR INTERCITY PASSENGER TRANSPORTATION BY VTOL AIRCRAFT

IN FOUR VOLUMES:
Volume I: Summary and Method

Norman J. Asher
Elliot Wetzler
Seymour M. Horowitz
W. Bartz Schneider

August 1968

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INSTITUTE FOR DEFENSE ANALYSES
PROGRAM ANALYSIS DIVISION

IDA

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ABSTRACT

Aircraft demand and cost functions were estimated for six types of VTOL aircraft: conventional helicopter, compound helicopter, tilt rotor, tilt wing, stowed rotor, and fan or jet lift. From these functions total aircraft profit or loss as a function of the number of aircraft produced was calculated. Results were calculated for the 90 seat size of all six types; in additon, 30, 60, 120 and 150 seat sizes were analyzed for the fan or jet lift type.

The aircraft demand was calculated separately for each domestic city pair and then summed to obtain total domestic demand. The domestic demand was then increased by a constant ratio to account for export sales. Demand is based on air traffic for 1985, the estimated final year of production for these first generation intercity VTOL aircraft.

Volume III presents generalized aircraft demand by city pair as a function of VTOL aircraft fare, block time and number of seats. With these data, the user of this report can determine the demand for any VTOL passenger transport design.

Descriptors

VTOL Aircraft	Fares	Vertiports
Civil	Value of Time	Operating Costs
Economics	Travel Preferences	Aircraft Cost
Air-Travel Demand	Trip Times	

FOREWORD

In December, 1966, the Military Aircraft Panel of the President's Science Advisory Committee asked the Institute for Defense Analyses (IDA) for advice in formulating the government's future VTOL aircraft program. As a result of this request IDA undertook studies of both civil and military markets for VTOL aircraft. This Report covers the civil market analysis which was sponsored by IDA. When the military transport study is completed, the optimal aircraft characteristics can be compared with the civil aircraft to determine whether a single basic aircraft type can efficiently meet the requirements of both markets.

In addition to the principal authors listed on the title page the following personnel made valuable contributions to the study: Mr. Samuel E. Eastman prepared the appendix on Airport and Vertiport Costs, Mr. Joseph P. Severo did the computer programming, and Misses Eloise Hally and Mary Liz Wachendorf served as research assistants on several portions of the study.

Norman J. Asher
Project Leader

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SUMMARY AND RESULTS

Aircraft demand and cost functions were estimated for six types of VTOL aircraft: conventional helicopter, compound helicopter, tilt rotor, tilt wing, stowed rotor, and fan or jet lift. Results were calculated for the 90 seat size of all six types and for the 30, 60, 120, and 150 seat sizes of the fan or jet lift type. The results are shown in Figures S1 through S10.

The domestic aircraft demand was calculated by individual city pairs and then summed. This domestic demand was then increased by a constant ratio to account for export sales. This total demand as presented in Figures S1 through S10 is based on demand in 1985, the estimated final year of production for these first generation intercity VTOL aircraft.

Aircraft demand is shown both with a frequency requirement of six round trips per day between city pairs and with no frequency requirement. The frequency requirement has little effect in percent on numbers of aircraft demanded when the demand is large (at low prices for the faster types) but it does significantly reduce the percent of aircraft when demand is small (at high prices for the slower types.)

We have not required a minimum number of passengers for each city. Such a requirement would take into account the level of traffic required to justify the cost of providing a city-center vertiport. If this level of traffic is less than that corresponding to six round trips per day, the aircraft demand would be further reduced because VTOL operations at some cities with service to only one other city would be eliminated.

The selling price of each aircraft type is shown both with and without engine nonrecurring costs. The selling price is based on production of each type for the civil market only. If a common basic aircraft

could be sold in the military market as well, the civil selling price would be lower than shown. Moreover, the price reduction would be largest if the aircraft were first developed and produced in volume for the military market. In such a case, both the civil development costs and the recurring costs would be much less because of the benefit of the "learning" effect from the military production program. Total program expenditures and revenues have been calculated from Figures S1 through S10 and are presented in Figures S11 through S20.

All results shown in these figures are based on the assumption that the entire VTOL market is satisfied by production of a single aircraft type (and size). If more than one aircraft split this market, the selling price curve for each competing type would remain as shown, but the demand curve would be lower. (For instance, it would be half as great if two competing aircraft split the market equally.) Conclusions for each type in order of increasing cruise speed are discussed below:

<u>Helicopter and Compound Helicopter</u> (Figures S1, S2, S11, S12). These types do not appear attractive economically, basically because they are too slow. Being slow, they lose their initial time saving over the conventional fixed wing transport at around 250 miles. As a result, the number of city pair routes on which they can compete is greatly reduced. Further, the city pairs on which they can compete are at the shorter distances and therefore relatively few aircraft are required to carry large numbers of passengers on these routes. A high percent of subsidy would be required for a helicopter or compound helicopter program. This program would be vulnerable to the introduction of one of the faster VTOL types which would be both faster and cheaper than either of the helicopter types.

<u>Tilt Rotor</u> (Figures S3, S13). This type appears to be marginally profitable. Since its disc loading is comparable to that of helicopters, its noise characteristics should be in the most acceptable class. The tilt

rotor has been flown experimentally so its technical risk is moderate.

Tilt Wing (Figures S4, S14). This type is somewhat more attractive economically than the tilt rotor type. However, its noise characteristics are considerably worse than those of the tilt rotor. The tilt wing aircraft has been flown experimentally so its technical risk is moderate.

Stowed Rotor (Figures S5, S15). This type lies between the tilt rotor and tilt wing economically and its noise characteristics should be in the most acceptable class. However, the stowed rotor has never been flown so its technical risk is high.

Fan or Jet Lift (Figures S6, S7, S8, S9, S10, S16, S17, S18, S19, S20). This type was selected for size optimization because it was believed to be the most attractive economically. Subsequently, however, it proved to be less attractive economically than the stowed rotor, tilt wing, or tilt rotor, but better than the helicopter types. The poor showing of the fan or jet lift is due to its relatively high price, caused by its relatively high engine costs. Its noise characteristics should be considerably worse than any of the rotor types and somewhat worse than the tilt wing. This type of aircraft has been flown experimentally so its technical risk is moderate.

Figures S16 through S20 indicate that with no frequency requirement the minimum program loss occurs in the 60 to 90 seat size; for the 120 and 150 seat sizes the minimum program losses are only moderately higher. With a minimum frequency requirement of six round trips per day, the minimum program loss still occurs in the 60 to 90 seat size, while losses for the 120 and 150 seat sizes are significantly worse. The optimum seat size of 60 to 90 is smaller than might be expected intuitively. As the size is increased, the nonrecurring costs increase and the number of aircraft needed to carry the passengers is reduced; both effects increase the nonrecurring costs that must be amortized for each aircraft sold. Further, since not so many aircraft are needed, the recurring-cost learning effe :s are reduced. The

nonrecurring costs are lower for the tilt rotor, tilt wing, and stowed rotor types, so their optimum sizes would be somewhat higher than for the fan or jet lift type--probably about 100 seats.

The six VTOL types are ranked in Table S1. The first column is based on Figures S1 through S20 and shows economic ratings--determined only by the fare and speed characteristics of the aircraft. The degree of uncertainty in the estimates of aircraft characteristics and costs, as well as of passenger demand, weakens the confidence in this ranking. Small relative differences would change the ranking particularly for the tilt rotor, tilt wing, and stowed rotor types. The second column ranks noise and air pollution levels in landing and takeoff.[1] Since both are basically a function of disc loading, the amount of air pollution increases with noise level. Four of the types hover like a helicopter and should have helicopter-like noise and air pollution levels. The other two types have considerably worse noise and air pollution levels. High noise levels would have a major adverse effect on passenger demand for VTOL service if the aircraft were forced to operate from vertiports well removed from the city centers. Design characteristics to reduce noise levels will probably involve major weight (and therefore cost) penalties. The third column deals with technical risk. As could be surmised, the two helicopter types involve little technical risk; the stowed rotor, the only type that has not been flown, may involve the highest technical risk. The other three types are intermediate in this category.

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1. For noise contours of various VTOL aircraft see NASA Contractor Report NASA CR-986, "Study of Aircraft in Short Haul Transportation Systems," January 1968; (prepared by the Boeing Co., Renton, Washington). This report indicates the following ground areas where the noise level is at least 90 PNdB:

tilt rotor:	.06 sq. mi.
tilt wing:	.35 sq. mi.
jet lift:	1.61 sq. mi.

Some unpublished data, indicate that the conventional helicopter and the lift fan aircraft would produce nearly the same noise level.

We have assumed the Boeing data to be correct in our ranking.

Table S1

RANKING BY AIRCRAFT TYPE

Aircraft	Economic (Fare/Speed)	Noise/Air Pollution	Technical Risk	Over-All
Helicopter	6	1	1	6
Compound Helicopter	5	1	2	5
Tilt Rotor	3	1	5	1
Tilt Wing	1	5	3	3
Stowed Rotor	2	1	6	2
Fan or Jet Lift	4	6	4	4

The final over-all ranking requires a subjective weighting of the three basic categories. We have ranked the tilt rotor highest because it is only slightly worse economically than the tilt wing or stowed rotor; furthermore, it produces considerably less noise and air pollution than the tilt wing and involves much less technical risk than the stowed rotor.

Nevertheless, the stowed rotor seems to offer the greatest potential if it can be successfully developed, since economically it is better than the tilt rotor and is much quieter than the tilt wing. Because it may offer the greatest potential, it would be valuable to validate its characteristics by a flight test program. It should then be reevaluated before a production program is undertaken. Depending on the time required for stowed rotor development, the tilt rotor or one of the other types might be produced as a first generation vehicle and the stowed rotor might replace it as the second generation vehicle.

Figures S1 through S20 are based on the assumption that nonrecurring costs are allocated over the number of aircraft produced and that all aircraft produced are sold at the same price. Commercial aircraft historically have been priced in this manner. In this way the maximum total program profit is shown on Figures S11 through S20 at the quantity where the maximum surplus of revenues over expenditures occurs. (For unprofitable programs, minimum program loss occurs where minimum deficiency of revenues under expenditures occurs.)

An alternate (and much less likely) pricing assumption is that the manufacturer would price the aircraft according to his marginal recurring costs. This method is generally used in US military aircraft procurement where the government pays for the aircraft nonrecurring costs and then buys groups of aircraft (usually in one year production increments) at the marginal recurring cost for each group purchased. The results of this pricing method are shown in Figures S21 through S30. This method brings about the sale of more aircraft but eliminates recovery of the nonrecurring costs. Accordingly, from the manufacturer's point of view, a total program loss equal to the nonrecurring costs results. However, the program could still be profitable to the total economy if the consumer surplus resulting from operation of the aircraft substantially exceeded the nonrecurring costs.

Volume III presents generalized aircraft demand by city pair for the top ranking 86 city pairs. Although a few additional aircraft might be demanded if more city pairs were considered, the number of additional aircraft compared with the demand for these top 86 city pairs would generally be less than ten percent. It is felt that this small additional demand would be offset by unavailability of verti-ports in some of the top 86 city pairs and that therefore the demand as shown for these city pairs closely represents the total domestic demand.

Volume IV presents the aircraft demand by city pair for the specific aircraft shown in Figures S1 through S30. The total demands shown in Figures S1 through S30 are the sums of the individual city-pair demands given in Volume IV plus an allowance for the export market. The importance of conventional airport distance from city center on VTOL demand can be seen in the individual city-pair results of Volume IV. For example, Table S2 shows that 5.7 helicopters are needed on the Chicago-Detroit route while only one is needed for Washington-New York even though the number of air passengers is almost four times higher on the Washington-New York route and the distances are comparable. The higher number of helicopters for Chicago-Detroit is required because the airports are much further from the city centers than they are in Washington and New York.

Table S2

NUMBER OF CONVENTIONAL HELICOPTERS DEMANDED
1985
90 Seat Size
Price = $4,000,000

Measure	Washington-New York	Chicago-Detroit
Distance (st. mi.)	205	237
Number of Air Passengers, 1965	1,457	392
Number of Helicopters demanded	1.0	5.7
Airport Distances from City Center (st. mi.)	3.9 and 5.4	8.3 and 17.3

The results of the study are based on the demand for 1985--the estimated final year of the aircraft production program. The demand for 1975 (the estimated year of initial service) will be less because of three factors: (1) the base CTOL demand will be less, (2) the passengers' value of time will be less, and (3) if a minimum frequency of service is required, fewer city pairs will be included. The base CTOL demand in 1975 is estimated at 3.07 ÷ 6.48 = 47 percent of the 1985 demand (see Section 3). Accordingly, neglecting the other two factors, the VTOL aircraft demand in 1975 would be 47 percent of the figures shown for 1985.

The effect of passengers' value of time in 1975 relative to 1985 on percentage passenger preference for the faster, more expensive mode is explained in Section 7. The 1975 percentage passenger preference for the most competitive VTOL aircraft would be roughly 85 percent of the 1985 level; however, for the less competitive types, where passengers would have to pay $8 or more per hour to save time, the 1975 percentage passenger preference would be only about 74 percent of the corresponding 1985 figures.

The two factors previously discussed will result in more city pairs being eliminated in 1975 than in 1985 if a minimum frequency of service is required. Further, more city pairs will be eliminated for the less competitive types than for the more competitive types.

A minimum frequency requirement of six round trips a day is estimated to eliminate ten percent more of the total demand for the four fastest VTOL types in 1975 than it would in 1985. The corresponding percentage estimated for the helicopter and compound helicopter is 20 percent.

The 1975 demand as a percent of the 1985 demand can thus be estimated as follows:

Four most competitive (highest speed) VTOL's:

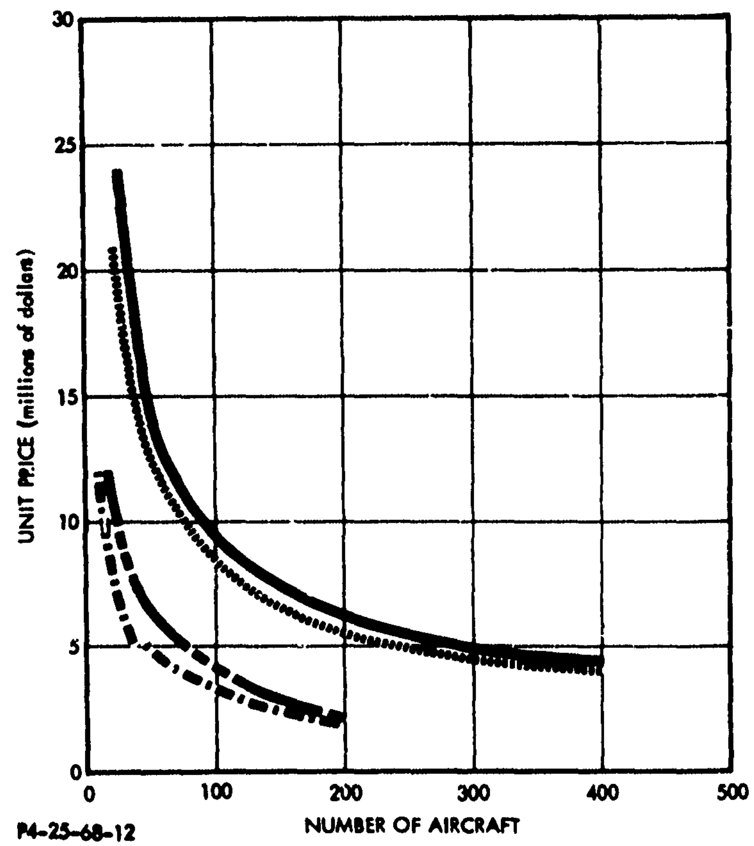
$.47 \times .85 \times .90 = 36\%$

Two least competitive (lowest speed) VTOL's:

$.47 \times .74 \times .80 = 28\%$.

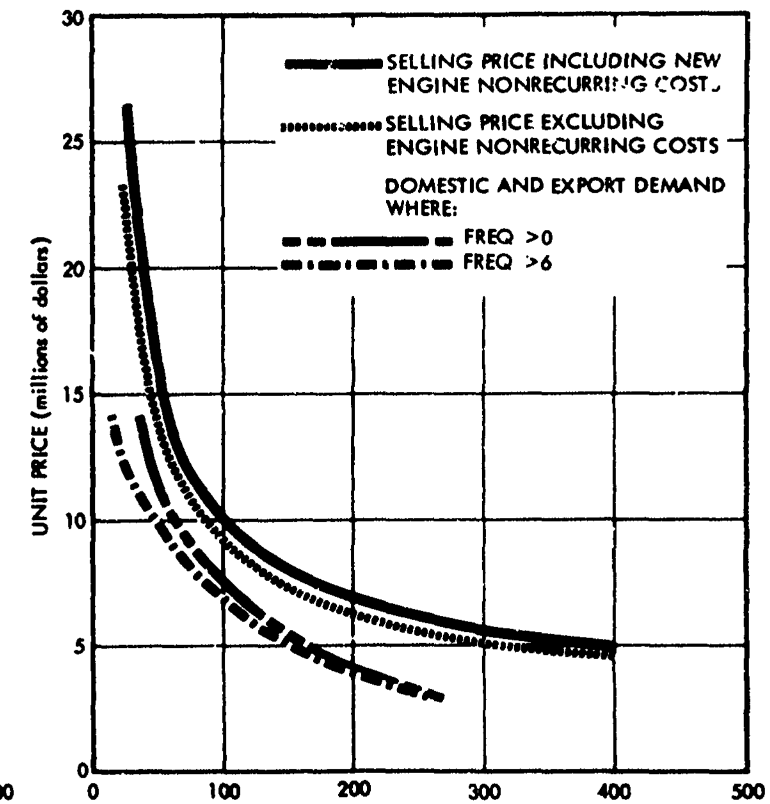
None of the VTOL aircraft types appear to be economically self sustaining by 1975; by 1985 three of the six types appear capable of economical operation. By then it is estimated that a market for 200-300 ninety-seat VTOL's will exist. These aircraft will serve approximately 50 US cities on 70 city-pair routes as well as some foreign routes. The next major step toward realizing VTOL service should be the construction and testing of prototype aircraft to reduce the substantial uncertainties in aircraft performance, investment costs, operating costs, and noise acceptability.

NUMBER OF AIRCRAFT DEMANDED VERSUS PRICE AND SELLING PRICE VERSUS NUMBER OF AIRCRAFT PRODUCED



90 SEAT CONVENTIONAL HELICOPTER
1985 DEMAND

FIGURE S1. 90 Seat Conventional Helicopter, 1985 Demand



90 SEAT COMPOUND HELICOPTER
1985 DEMAND

FIGURE S2. 90 Seat Compound Helicopter, 1985 Demand

NUMBER OF AIRCRAFT DEMANDED VERSUS PRICE AND SELLING PRICE VERSUS NUMBER OF AIRCRAFT PRODUCED

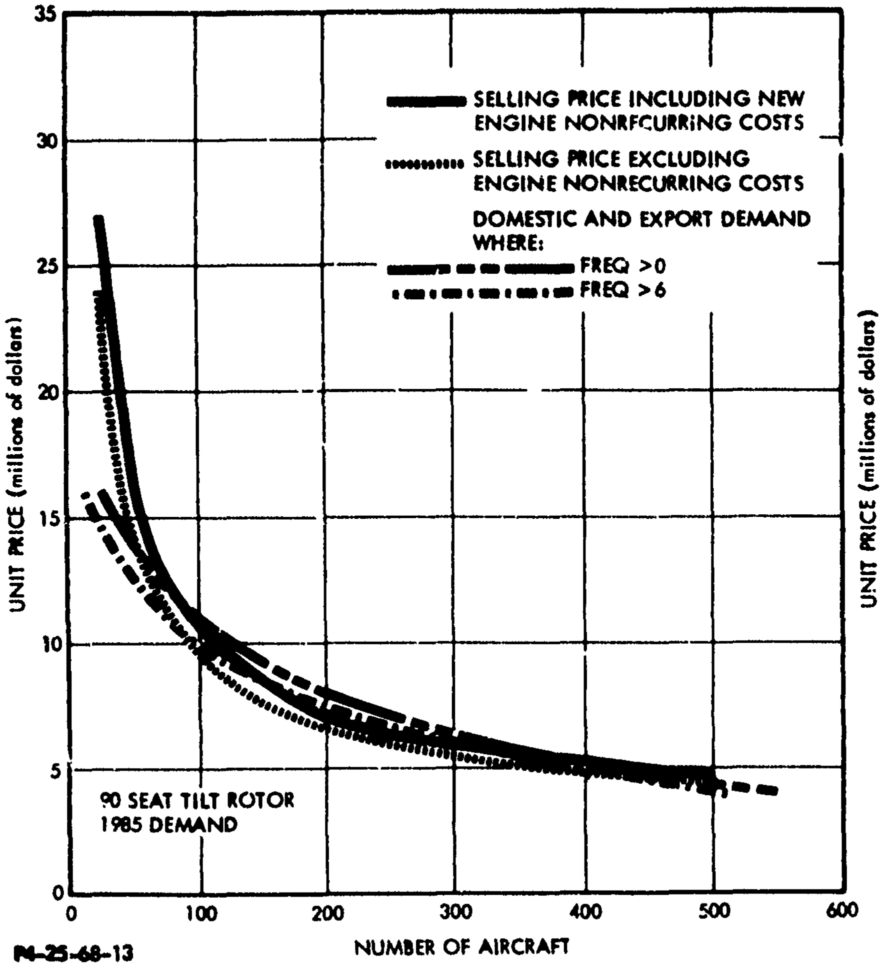


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FIGURE S3. 90 Seat Tilt Rotor, 1985 Demand

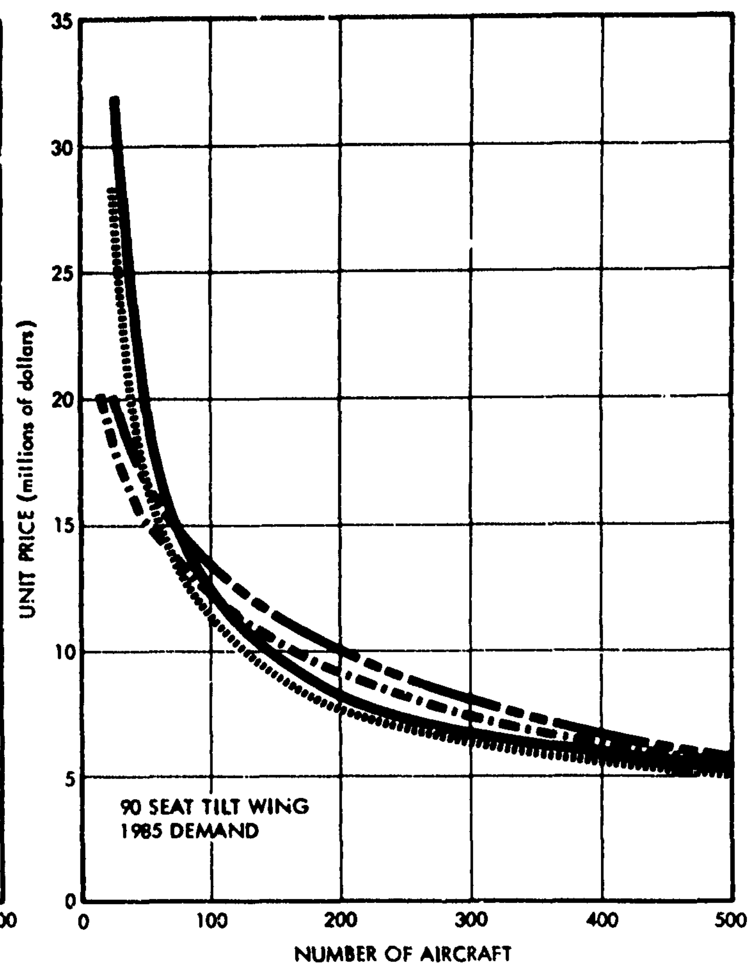

FIGURE S4. 90 Seat Tilt Wing, 1985 Demand

NUMBER OF AIRCRAFT DEMANDED VERSUS PRICE AND SELLING PRICE VERSUS NUMBER OF AIRCRAFT PRODUCED

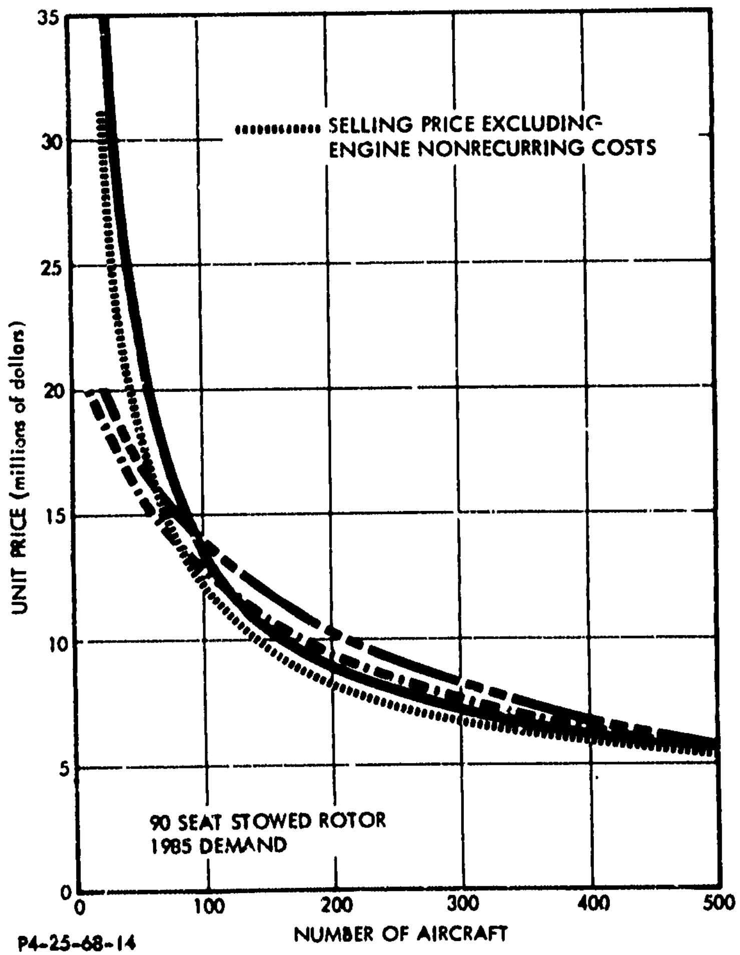

FIGURE S5. 90 Seat Stowed Rotor, 1985 Demand

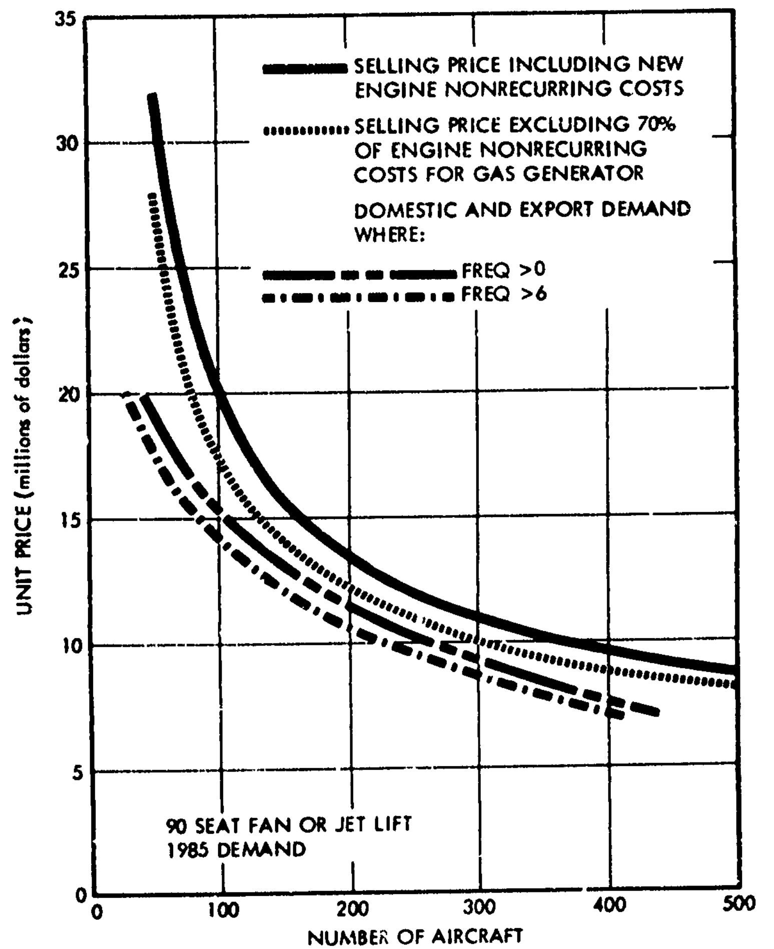

FIGURE S6. 90 Seat Fan or Jet Lift, 1985 Demand

NUMBER OF AIRCRAFT DEMANDED VERSUS PRICE AND SELLING PRICE VERSUS NUMBER OF AIRCRAFT PRODUCED

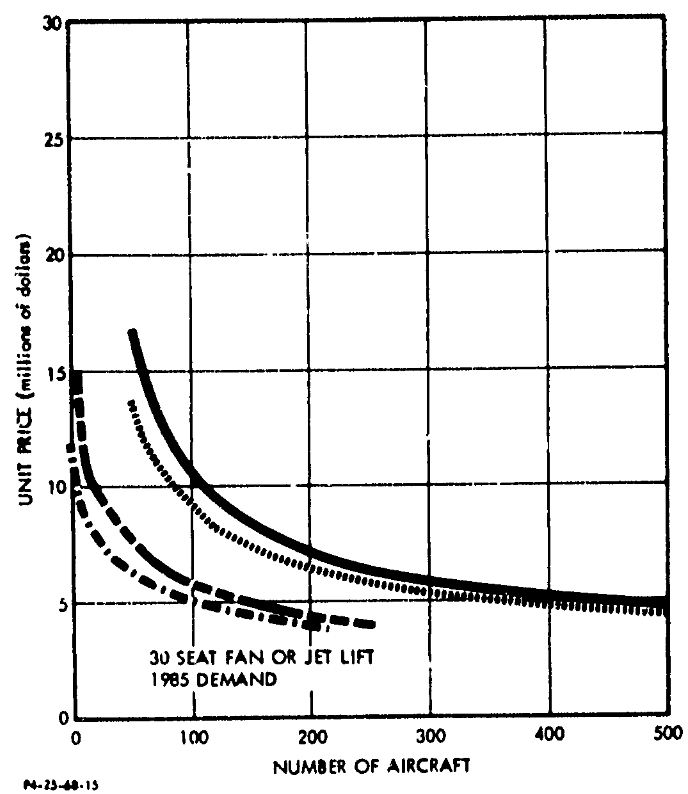

FIGURE S7. 30 Seat Fan or Jet Lift, 1985 Demand

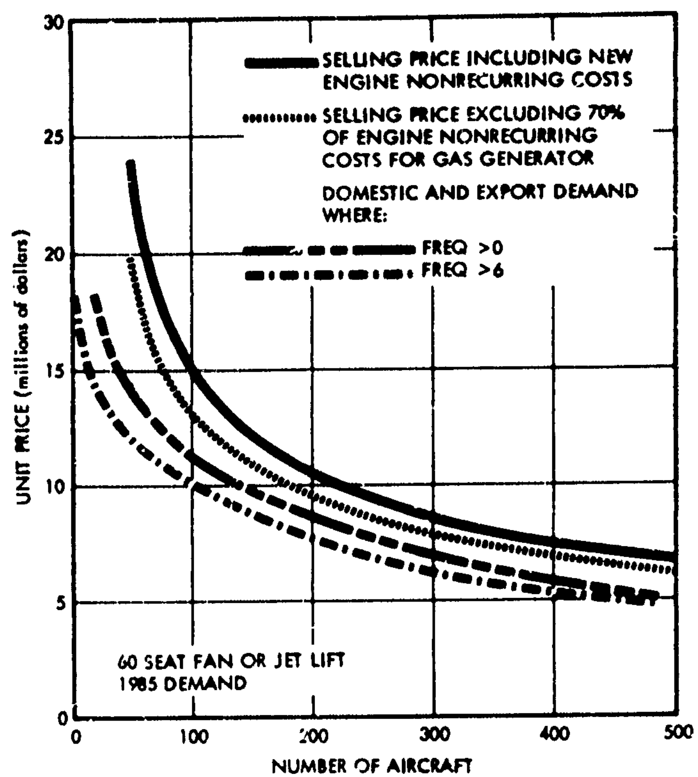

FIGURE S8. 60 Seat Fan or Jet Lift, 1985 Demand

NUMBER OF AIRCRAFT DEMANDED VERSUS PRICE AND SELLING PRICE VERSUS NUMBER OF AIRCRAFT PRODUCED

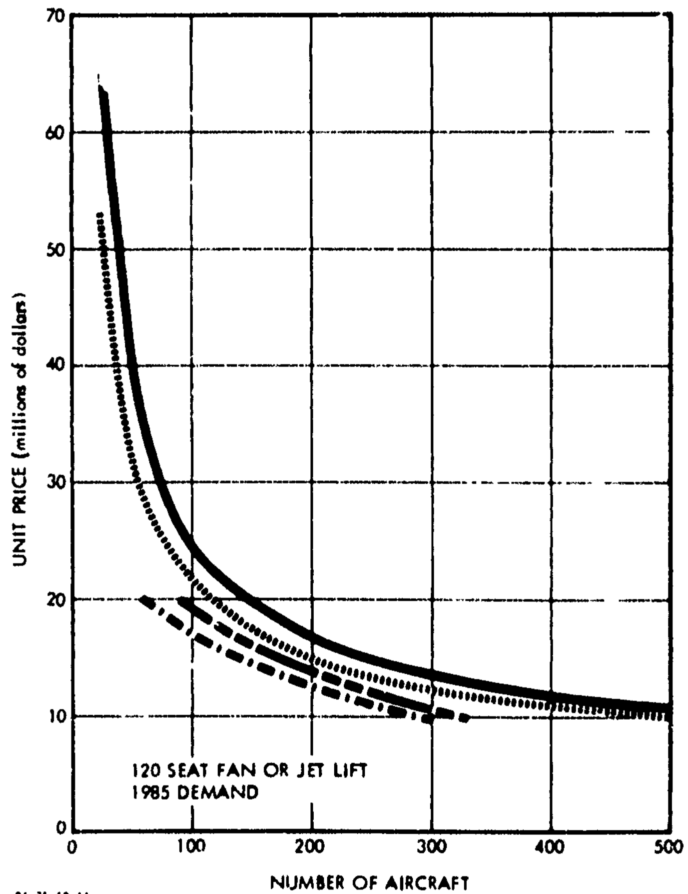

FIGURE S9. 120 Seat Fan or Jet Lift, 1985 Demand

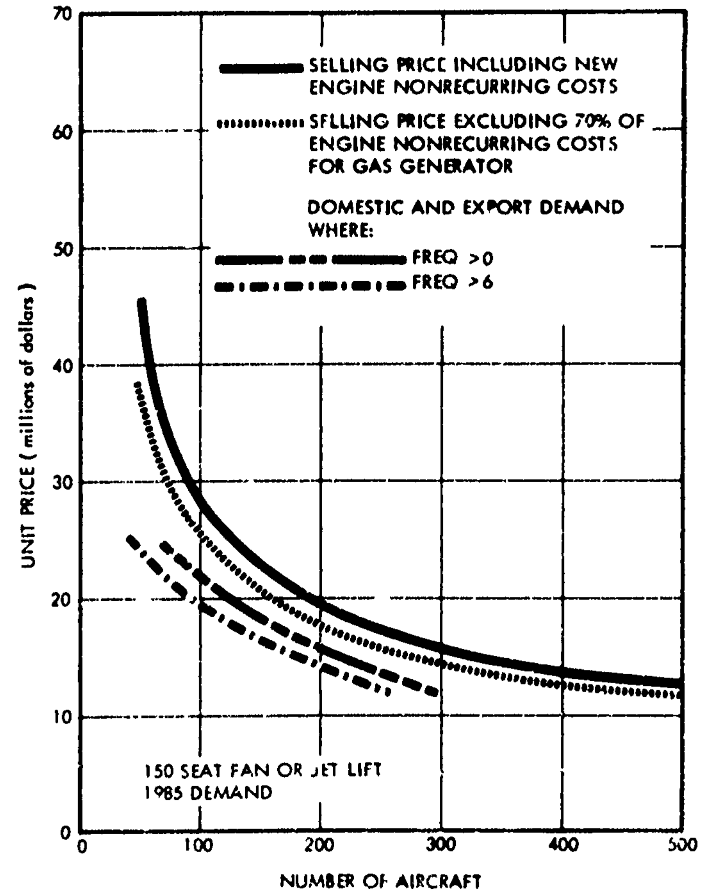

FIGURE S10. 150 Seat Fan or Jet Lift, 1985 Demand

TOTAL AIRCRAFT PROGRAM EXPENDITURES
AND REVENUES

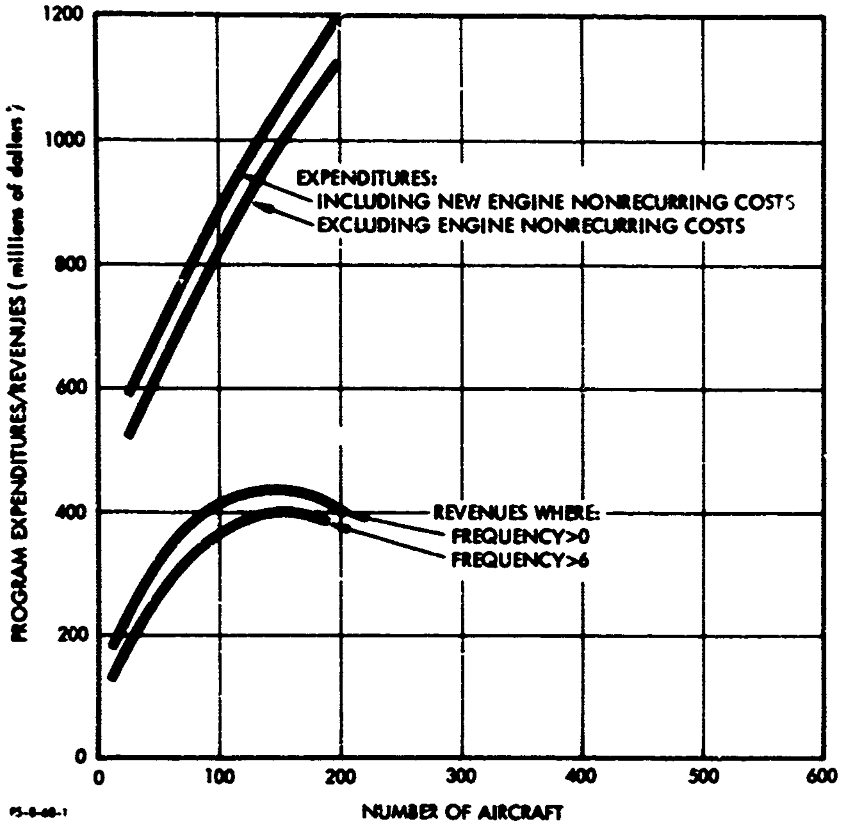

FIGURE S11. 90 Seat Conventional Helicopter, 1985 Demand

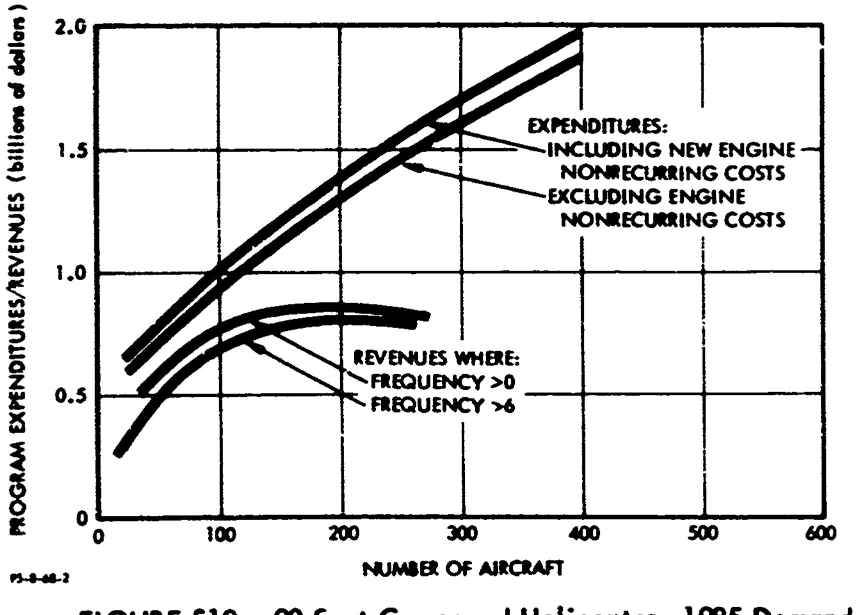

FIGURE S12. 90 Seat Compound Helicopter, 1985 Demand

TOTAL AIRCRAFT PROGRAM EXPENDITURES AND REVENUES

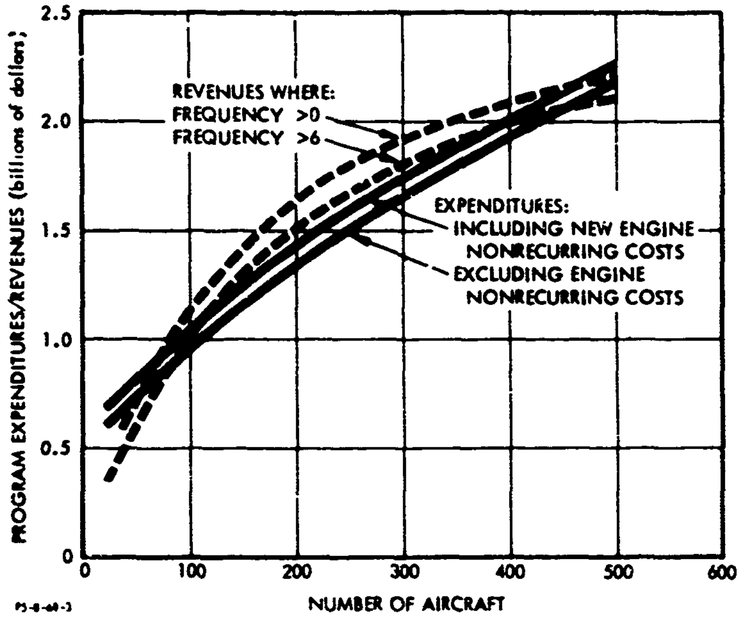

FIGURE S13. 90 Seat Tilt Rotor, 1985 Demand

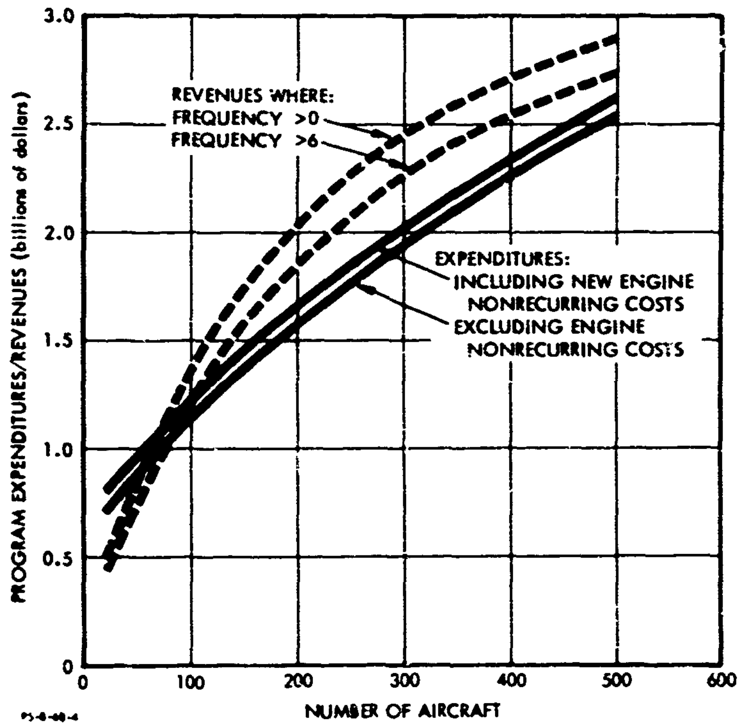

FIGURE S14. 90 Seat Tilt Wing, 1985 Demand

TOTAL AIRCRAFT PROGRAM EXPENDITURES AND REVENUES

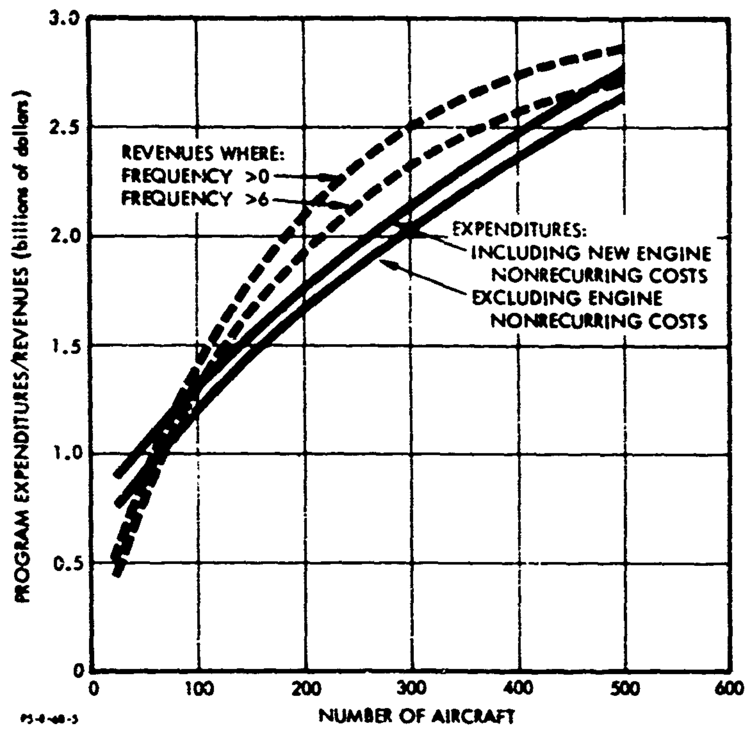

FIGURE S15. 90 Seat Stowed Rotor, 1985 Demand

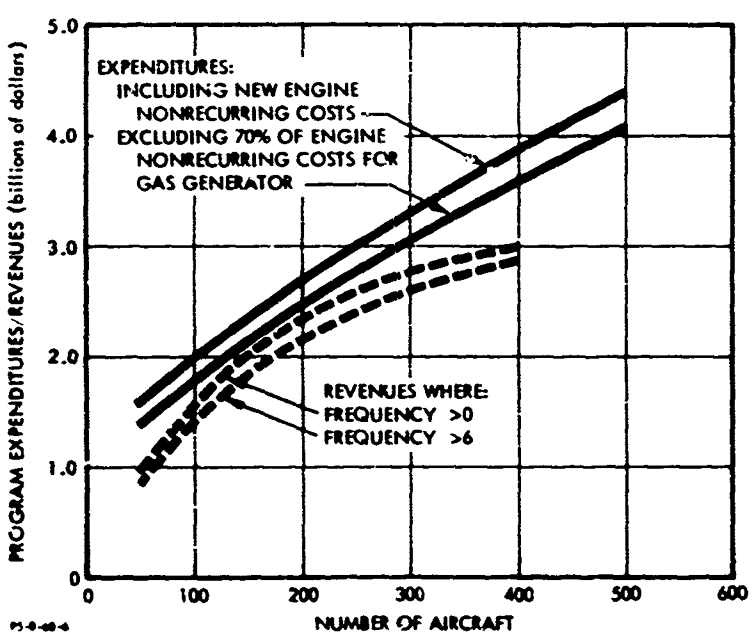

FIGURE S16. 90 Seat Fan or Jet Lift, 1985 Demand

TOTAL AIRCRAFT PROGRAM EXPENDITURES AND REVENUES

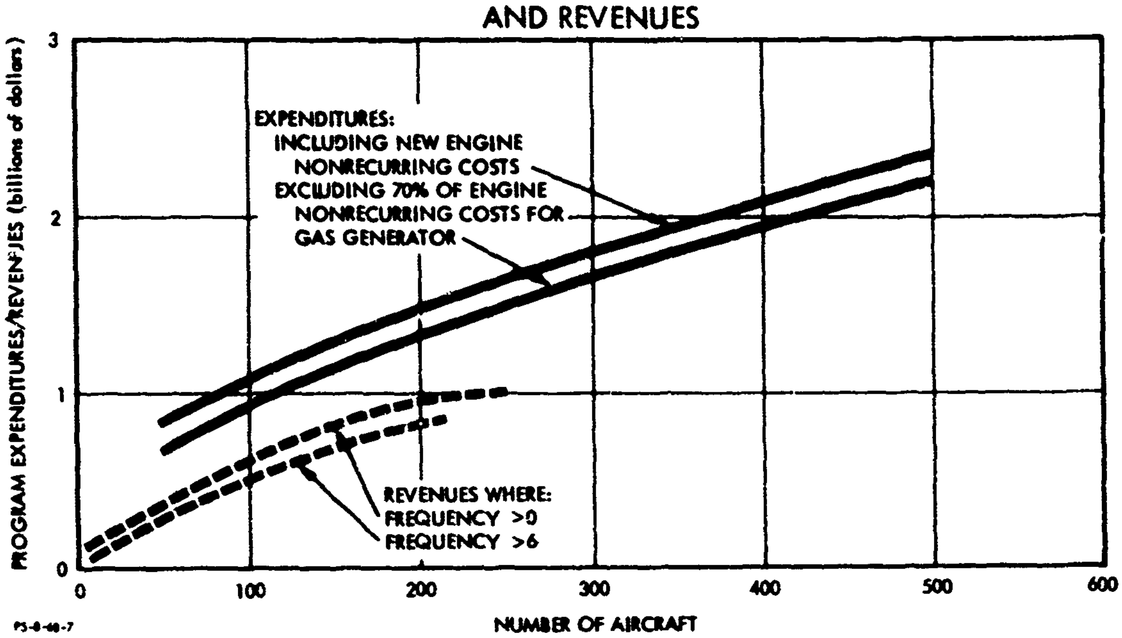

FIGURE S17. 30 Seat Fan or Jet Lift, 1985 Demand

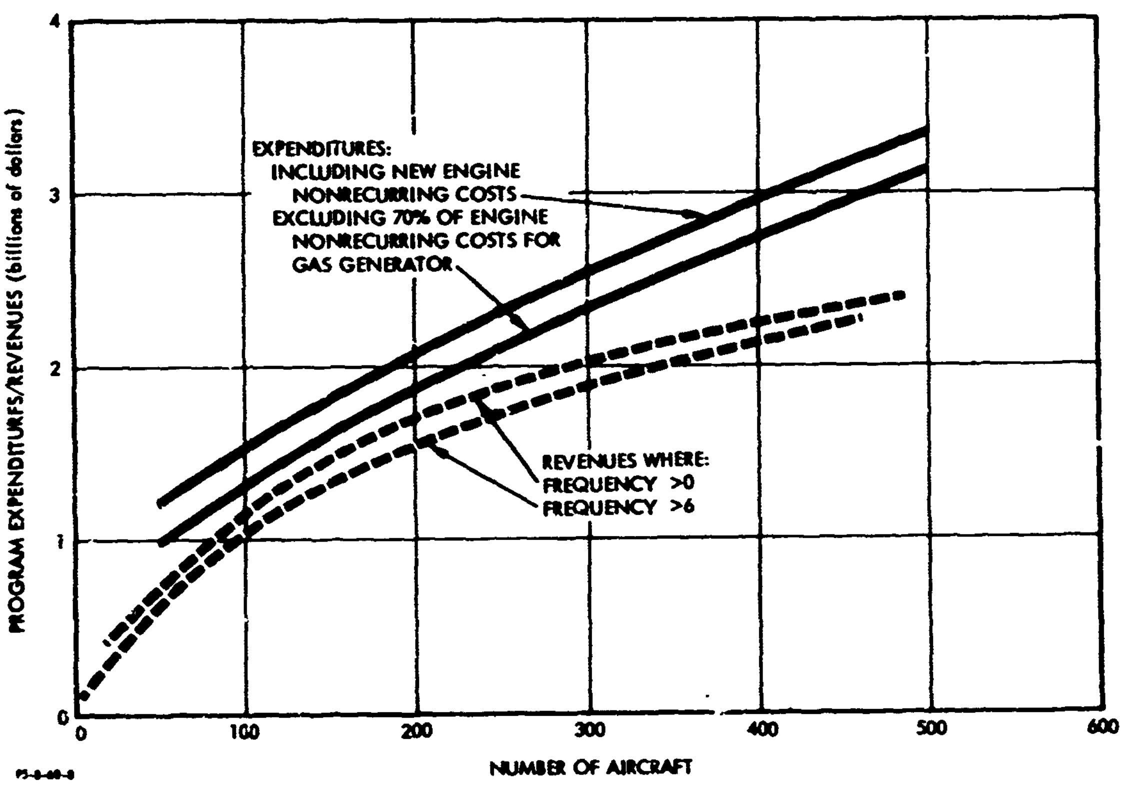

FIGURE S18. 60 Seat Fan or Jet Lift, 1985 Demand

TOTAL AIRCRAFT PROGRAM EXPENDITURES AND REVENUES

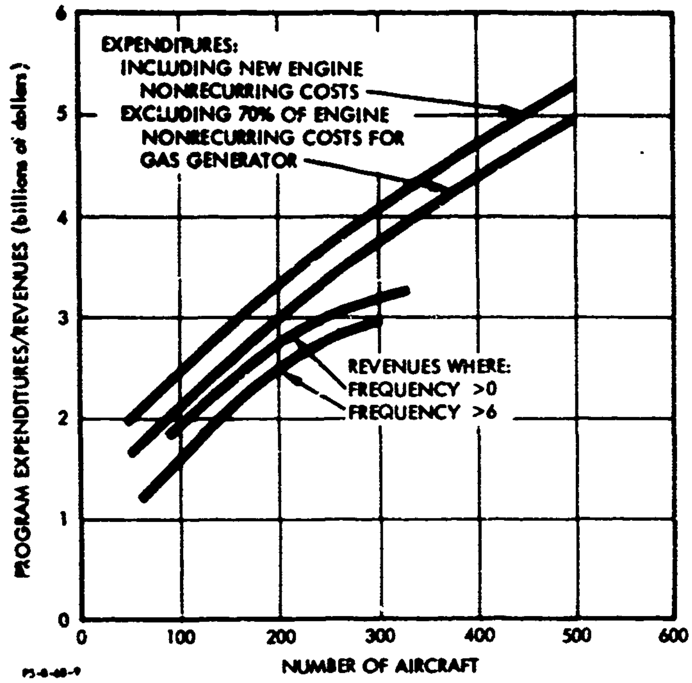

FIGURE S19. 120 Seat Fan or Jet Lift, 1985 Demand

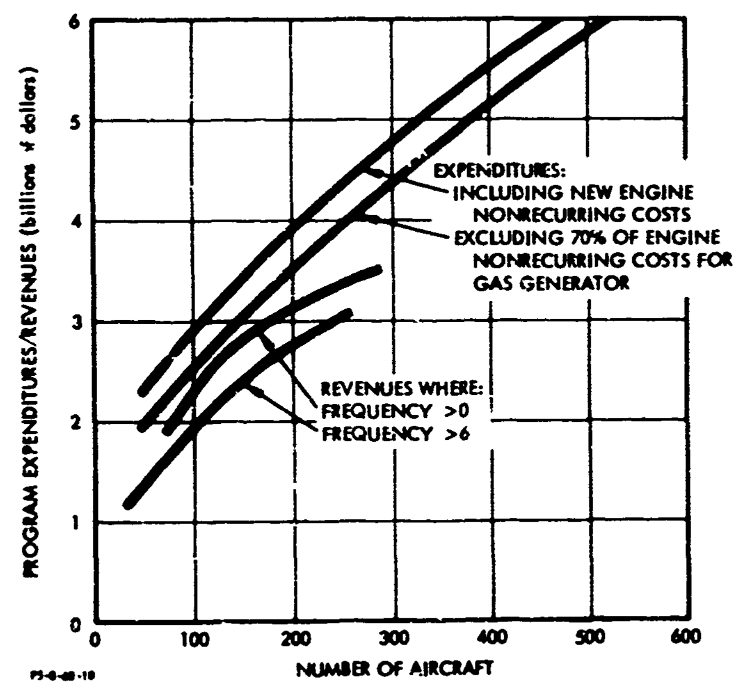

FIGURE S20. 150 Seat Fan or Jet Lift, 1985 Demand

NUMBER OF AIRCRAFT DEMANDED VERSUS PRICE AND MARGINAL RECURRING COST VERSUS NUMBER OF AIRCRAFT PRODUCED

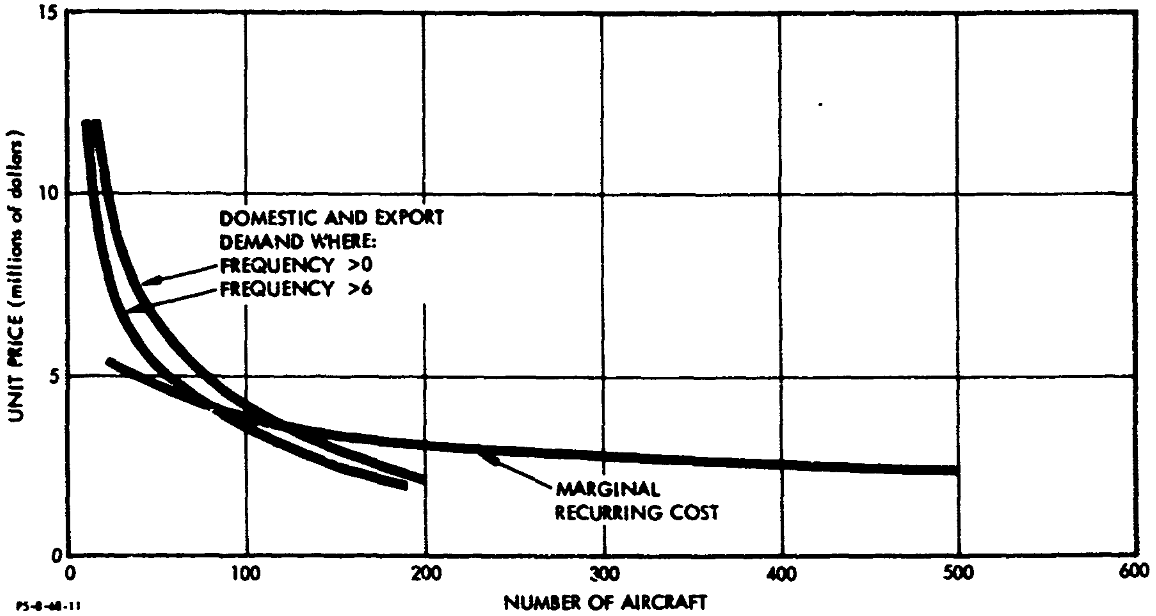

FIGURE S21. 90 Seat Helicopter, 1985 Demand

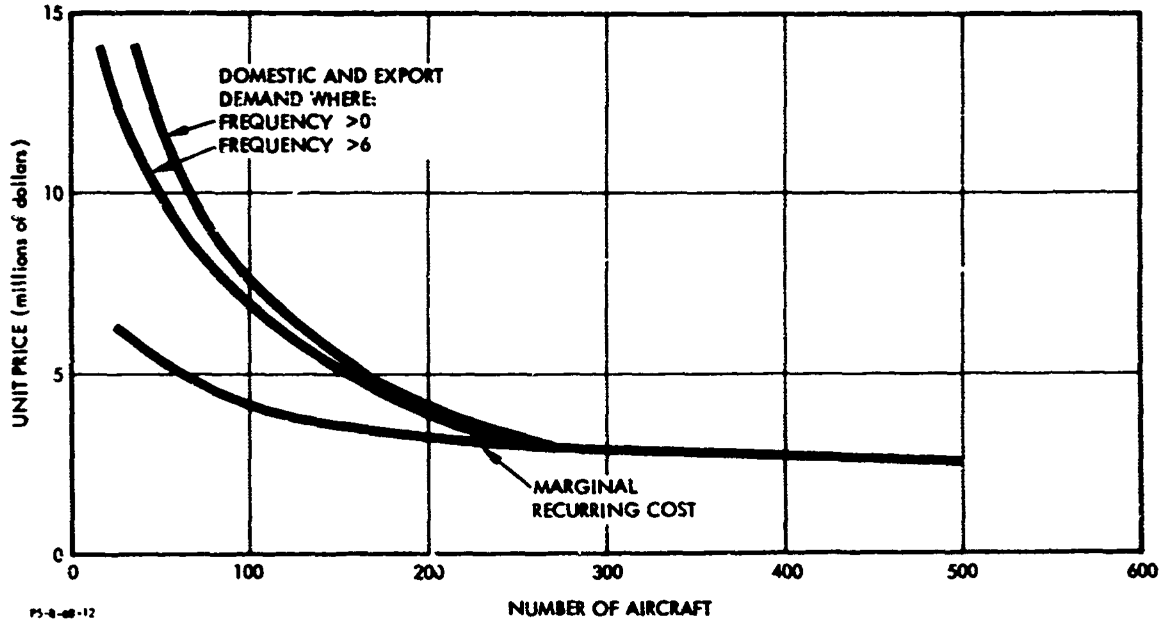

FIGURE S22. 90 Seat Compound Helicopter, 1985 Demand

NUMBER OF AIRCRAFT DEMANDED VERSUS PRICE AND MARGINAL RECURRING COST VERSUS NUMBER OF AIRCRAFT PRODUCED

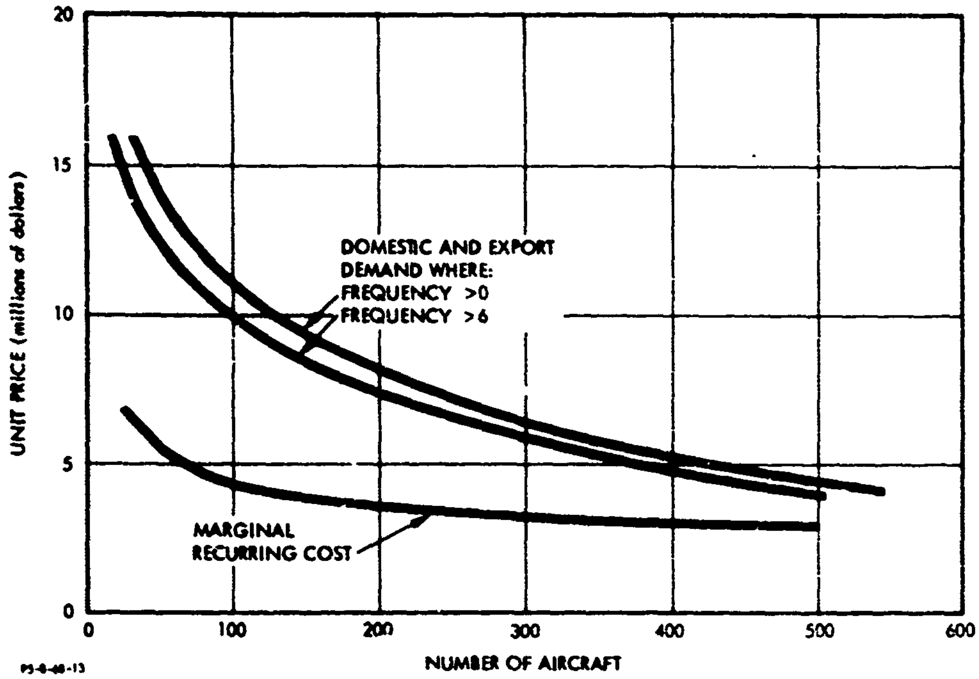

FIGURE S23. 90 Seat Tilt Rotor, 1985 Demand

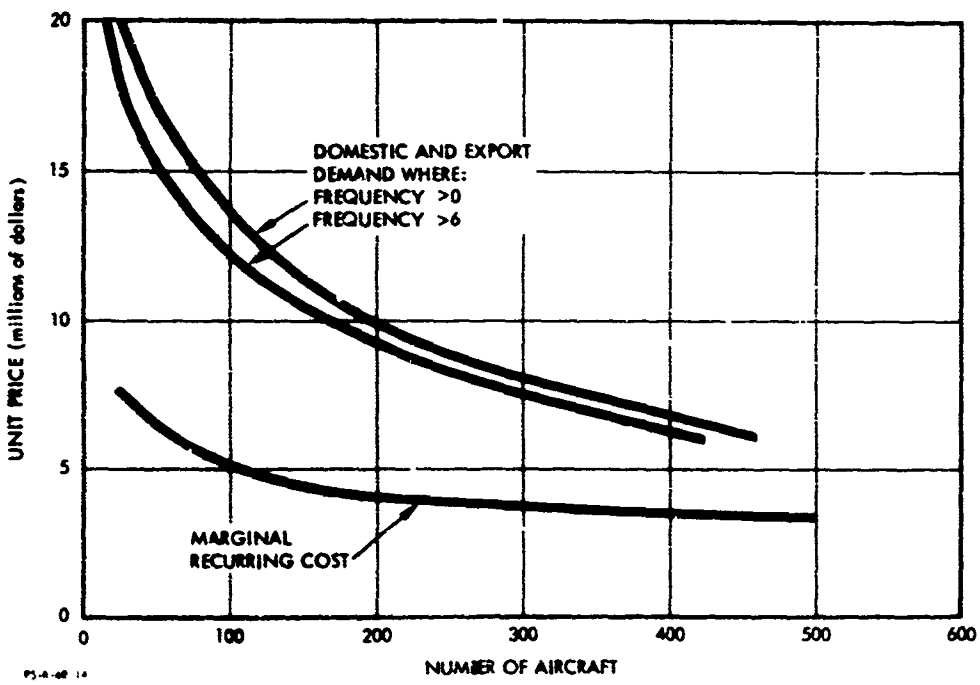

FIGURE S24. 90 Seat Tilt Wing, 1985 Demand

NUMBER OF AIRCRAFT DEMANDED VERSUS PRICE AND MARGINAL RECURRING COST VERSUS NUMBER OF AIRCRAFT PRODUCED

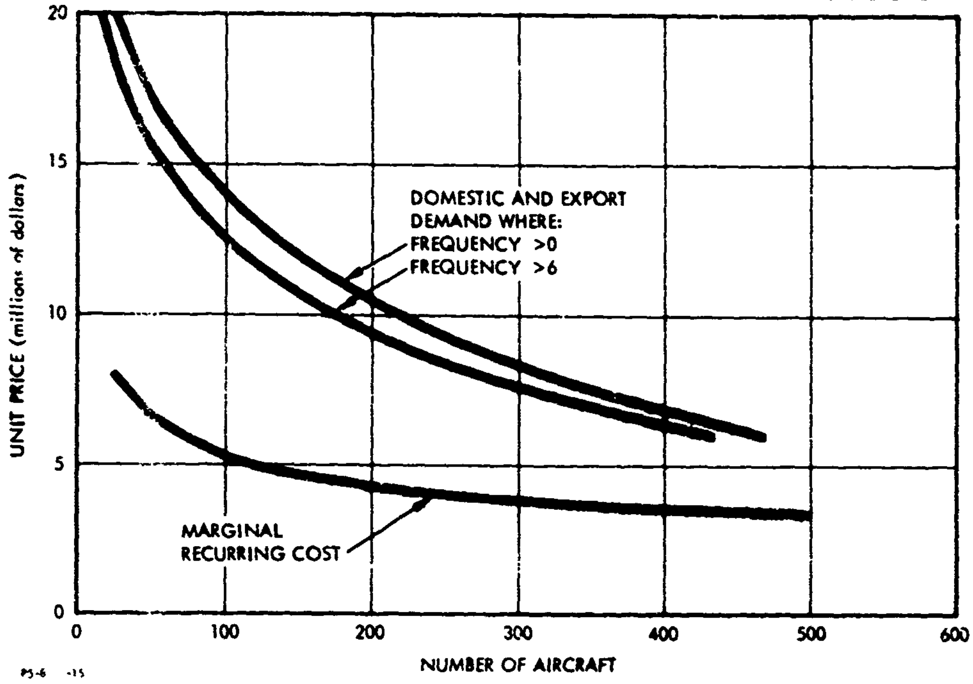

FIGURE S25. 90 Seat Stowed Rotor, 1985 Demand

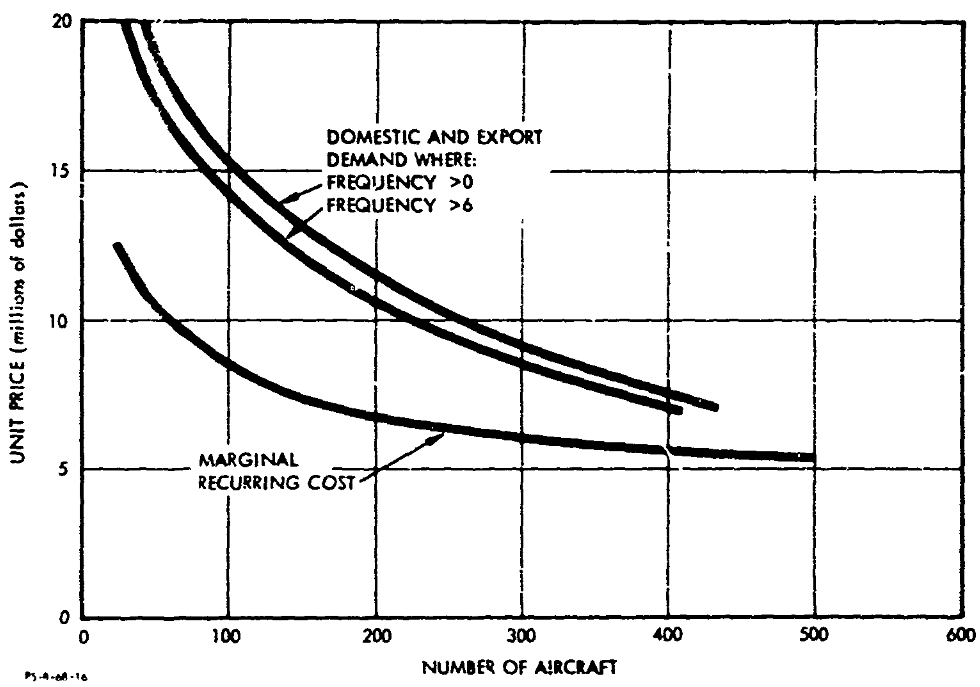

FIGURE S26. 90 Seat Fan or Jet Lift, 1985 Demand

NUMBER OF AIRCRAFT DEMANDED VERSUS PRICE AND MARGINAL RECURRING COST VERSUS NUMBER OF AIRCRAFT PRODUCED

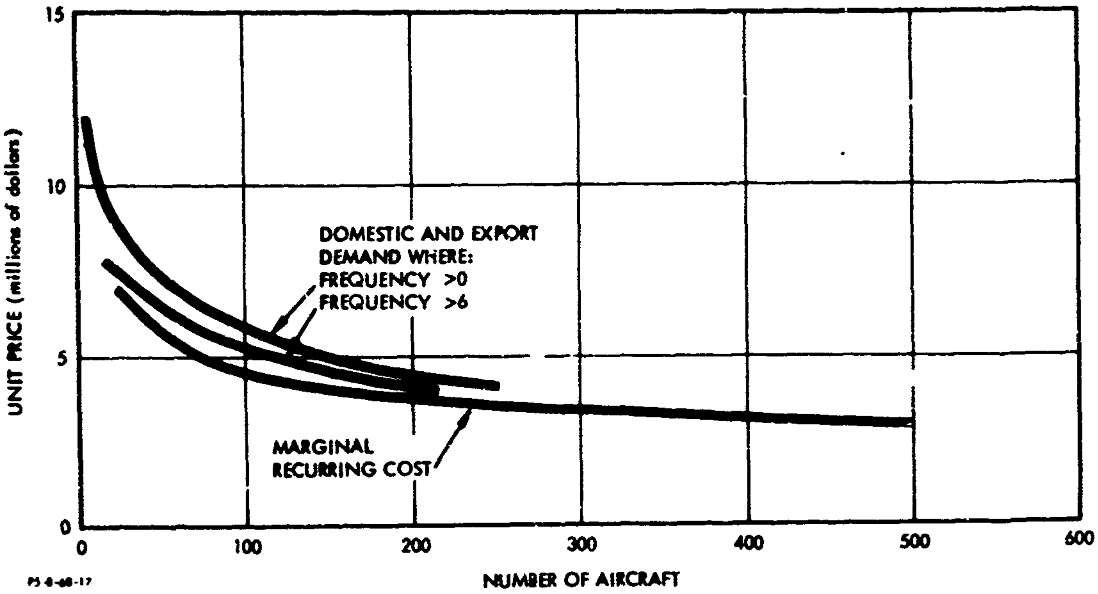

FIGURE S27. 30 Seat Jet Lift, 1985 Demand

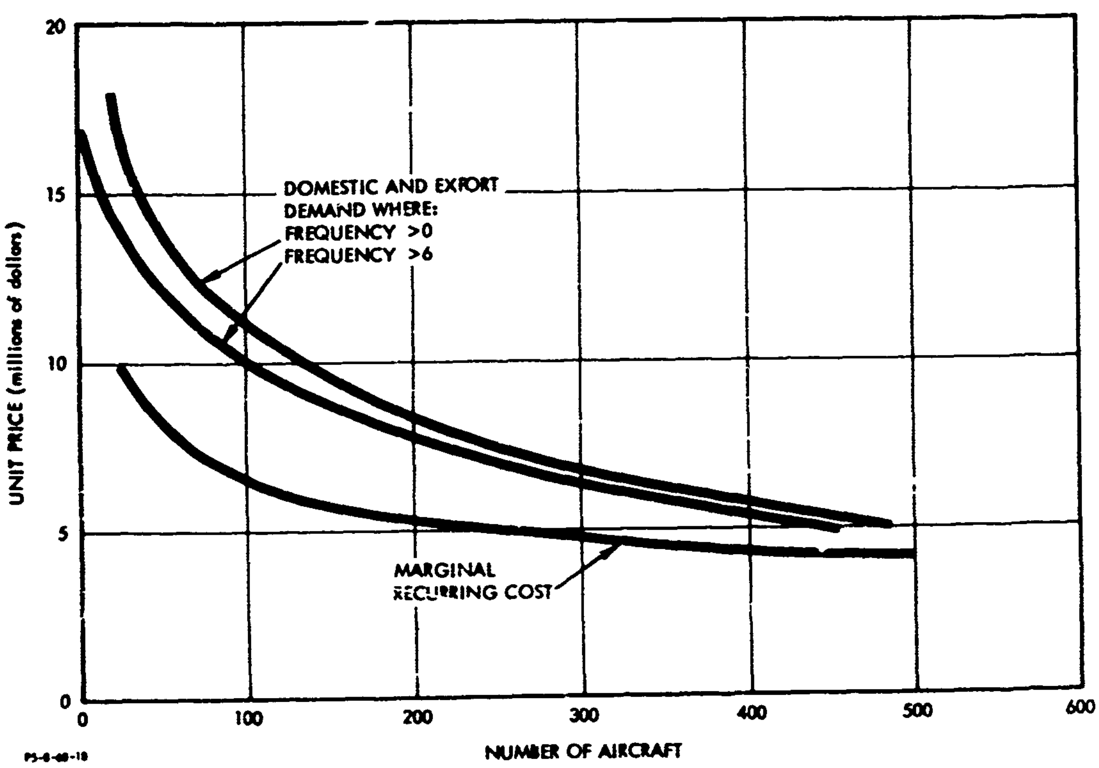

FIGURE S28. 60 Seat Fan or Jet Lift, 1985 Demand

NUMBER OF AIRCRAFT DEMANDED VERSUS PRICE AND MARGINAL RECURRING COST VERSUS NUMBER OF AIRCRAFT PRODUCED

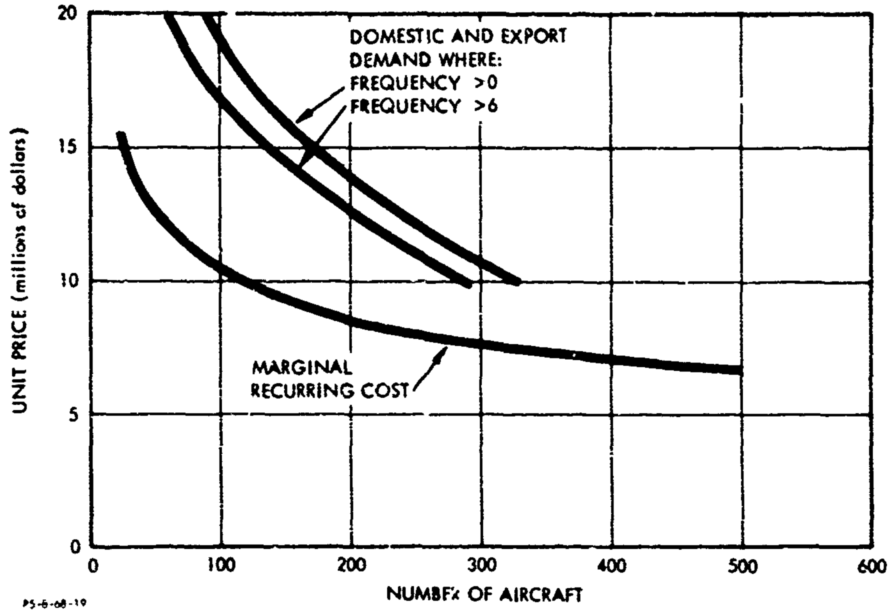

FIGURE S29. 120 Seat Fan or Jet Lift, 1985 Demand

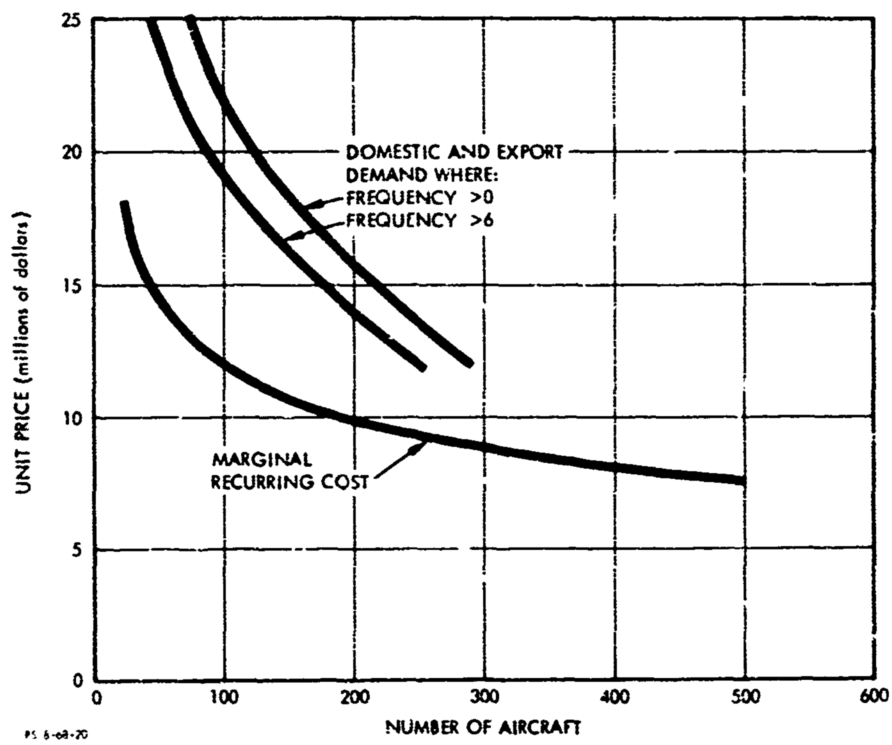

FIGURE S30. 150 Seat Fan or Jet Lift, 1985 Demand

1

INTRODUCTION

This Report presents an analysis of the demand for city-center to city-center passenger transport service by vertical takeoff and landing (VTOL) aircraft. This service is believed to comprise the most promising market for civil VTOL transports. If the VTOL aircraft are not competitive in this mission they will probably not be competitive in other civil transport roles. If they are competitive, there may be some additional market demand for other civil roles, such as transport to isolated points or from airport to downtown.

In this study we have assumed the VTOL's have overcome some very real problems involved in operating large aircraft in densely populated city centers--noise, air pollution, safety, and the availability of city-center vertiports. If the aircraft are not economically attractive under these favorable assumptions, further study is not warranted. However, if they are attractive then these additional problems must be solved before actual service can be realized.

Aircraft demand results in this study are estimated for the year 1985. The initial operational date for VTOL aircraft is estimated to be around 1975. Based on the past pattern of successful civil aircraft production programs it is estimated that the production program would continue through 1985 before the following generation of aircraft would enter service. Final demand for the aircraft will therefore be determined by the 1985 level of passenger demand. A means for estimating the initial demand in 1975 from the estimated demand in 1985 is presented.

Aircraft characteristics used in this study have been developed from a number of sources. These independent designs have been compared by type of aircraft and generalized industry trends have been developed

(see Appendix A). The range of VTOL cruise speeds considered cover those from the next generation helicopter (190 mile per hour cruise speed) to those of jet types with cruise speeds comparable to conventional subsonic jet transports (530 miles per hour). Total trip times as a function of intercity distance for several of these types and for conventional jet airplanes and ground vehicles are shown in Figure 1. These trip times include an average time for travel to and from the common carrier terminals. As can be seen in this generalized analysis, the helicopter loses its trip time advantage over the jet airplane at about 210 miles and the compound helicopter loses its advantage at about 330 miles. Because of the inefficient characteristics of these types at longer distances, the helicopter and compound helicopter types are assumed to have a design range of 250 miles. All the other VTOL types are assumed to have a design range of 500 miles. Our study provides for the analysis of varying seating capacities of the different VTOL configurations.

All dollars in this study are 1968 dollars unless otherwise noted. The mid-1968 consumer price index is estimated at 120 based on the historical index for 1957-59 = 100.

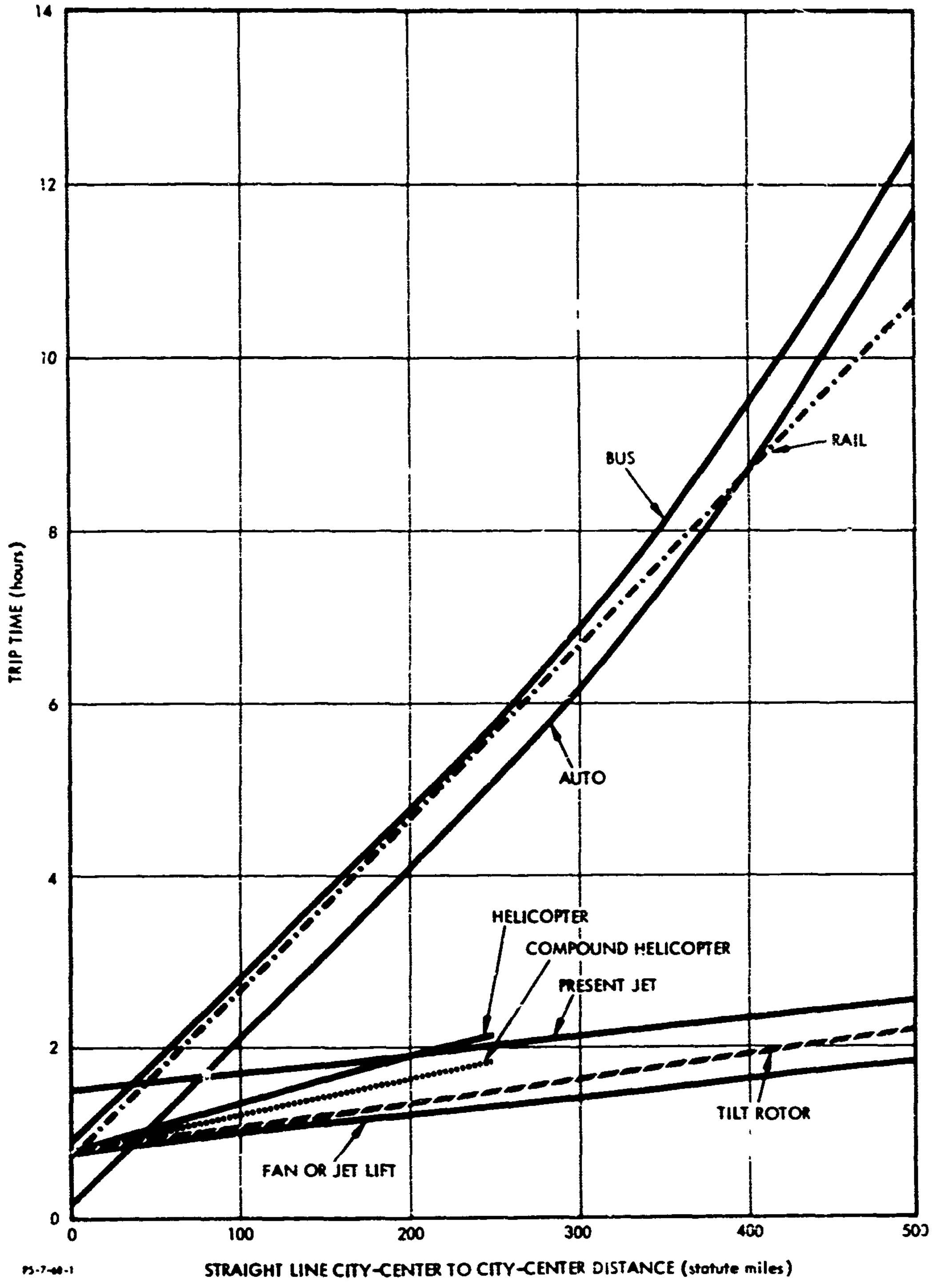

FIGURE 1. Total Trip Time Versus Intercity Distance

2

METHOD OF ANALYSIS

The basic method of analysis is presented in summary form in this section. Other sections of the Report present in detail many of the elements discussed briefly here.

Figure 2 presents the flow diagram for determining city-center to city-center VTOL passenger transport demand. The various steps involved are:

(1) The total domestic passenger demand based on conventional aircraft (CTOL) service is projected to 1975 and 1985.

(2) The 1965 origin-destination (OD) passenger demand by city pair is expanded to 1975 and 1985 levels in a manner compatible with (1) above.

(3) This traffic demand by city pair is further divided into the traffic demand from each segment of one city to each segment of the other city.

(4) CTOL and VTOL trip times and costs from each segment of one city to each segment of the other city are determined.

(5) The trip times and costs permit the calculation of costs of saving time by the faster mode. This figure represents the value a passenger must place on his time in order to justify selection of the faster, more expensive mode.

(6) The average value that passengers place on their time is believed to be approximated by the passengers' earning rate. Since earnings are expected to increase with time, an earnings distribution is defined for 1975 and 1985.

(7) Based on (5) and (6) above, passengers are divided between CTOL and VTOL service. This provides the number of air passengers by segment pair who will switch from CTOL to VTOL service.

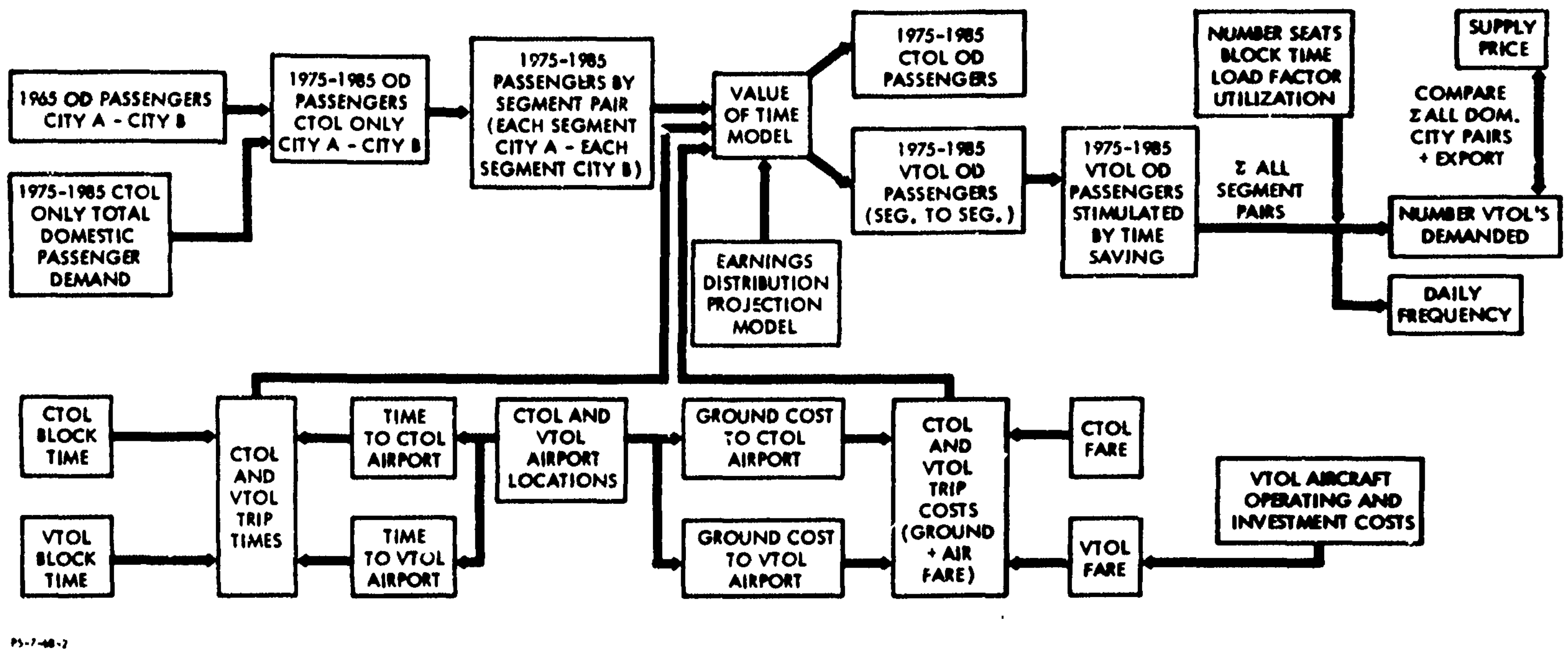

FIGURE 2. Relationships of Models, City A to City B

(8) Because of the additional time saving possible with VTOL service, a further increase in VTOL passenger demand is estimated to reflect a diversion of passengers from ground modes and some increase in the number of trips per passenger made by the original CTOL passengers who switch to VTOL.

(9) The VTOL passenger demand by segment pair is summed to obtain the total VTOL passenger demand by city pair.

(10) The aircraft productivity (number of seats, block time, load factor, utilization) determines the number of aircraft required to carry the city-pair passenger demand. These aircraft characteristics also determine the frequency of service. A minimum daily frequency requirement will be involved in determining the optimum aircraft capacity.

(11) The aircraft demand for all domestic city pairs is summed to obtain the total domestic aircraft demand.

(12) A quantity of aircraft for the export market is estimated and added to the domestic demand to obtain the total aircraft demand.

(13) The aircraft demand as a function of aircraft price is compared with the supply price of the aircraft to determine the economic feasibility of the program. The aircraft price is varied; this changes the VTOL fare, which changes the demand for aircraft. In this way the number of aircraft demanded can be determined as a function of the price of the aircraft. The supply price curve is determined with nonrecurring costs being averaged over varied production numbers of aircraft and recurring costs being estimated with applicable learning curves.

The computer program presented in Volume III conforms to the method of analysis outlined above.

3
AIR TRAFFIC FORECASTS

3.1 TOTAL DOMESTIC AIR TRAFFIC FORECAST

The traffic forecast of the FAA through the final forecast year (1977) was used as the domestic traffic forecast.[1] This forecast agrees closely with the CAB forecast as well as the forecasts made by a number of airlines, manufacturers, and the Institute for Defense Analyses. The forecast to 1985 was obtained by projecting the FAA forecast in a manner similar to the trend shown by some of the other forecasts which covered the 1985 time period. The forecast together with past actual revenue passenger miles (RPM's) from 1946 is shown in Figure 3.

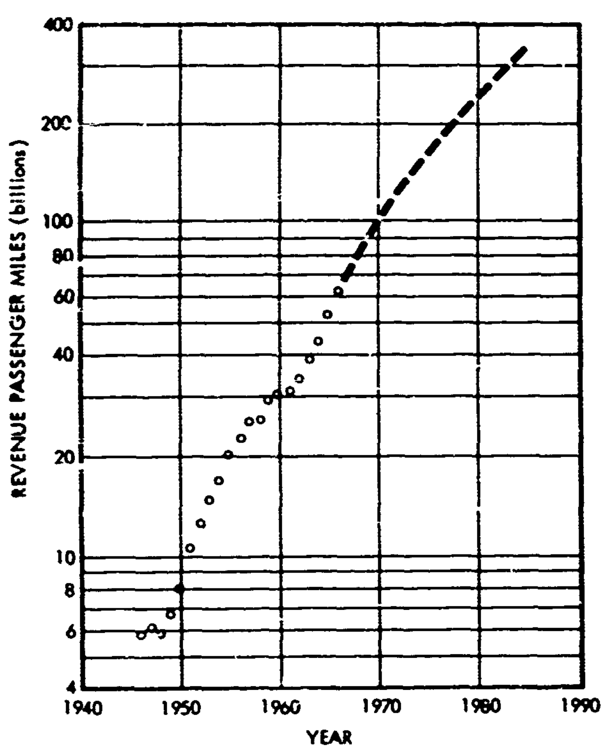

FIGURE 3. Domestic Traffic Forecast

1. Aviation Forecasts, Fiscal Years 1967-1977, January 1967

3.2 AIR TRAFFIC FORECAST BY CITY PAIR

Our method of analysis involves the use of actual passenger traffic by city pair. Because the 1966 airline strike affected the traffic on some city-pair routes more than on others, it was felt that 1965 origin and destination (OD) traffic by city pair[2] would be more representative of comparative city-pair traffic levels than the 1966 data. Using 1965 as a base year, the total domestic traffic forecast of Figure 3 indicates traffic in 1975 would be 3.07 times that of 1965, and traffic in 1985 would be 6.48 times that of 1965. Traffic by each city pair has been assumed to increase by these same ratios. Table 1 shows traffic estimated by this method for the top ranking 86 city pairs with intercity distances under 500 miles. Of course, the traffic growth by individual city pair can be expected to vary somewhat from the national average; however, for our study we have assumed that all city pairs will grow at the national average growth rate. The higher-than-average growth rates on some city pairs will be offset by the lower-than-average growth rates on others as they affect the total demand for aircraft.

To check the validity of the above assumptions, the 1965/1960 ratios of OD passengers were calculated for the 86 top ranking city pairs of Table 1; the average ratio was 1.70. Revenue passenger-miles for the total trunk and local service carriers (both scheduled and nonscheduled) were 30.6 and 52.8 billion in 1960 and 1965 respectively, so the 1965/1960 ratio of total domestic RPM's was $52.8 \div 30.6 = 1.73$. It can be seen that this figure is quite close to the average for the 86 city pairs of Table 1.

The future CTOL fare structure used in this study (Figure 5, page 23) assumes an increase in present fares under about 300 miles and a decrease at longer distances. According to our estimates of the fare elasticities, this differential fare change should result in a relatively lower

2. CAB Domestic-Origin Destination Survey of Airline Passenger Traffic, 1965.

Table 1

NUMBER OF PASSENGERS BY CITY-PAIR ASSUMING CTOL SERVICE ONLY

CITY PAIR	DISTANCE (ST.MI.)	NO. OF PASSENGERS OUTBOUND + INBOUND (000) 1965	1975 (x 3.07)	1985 (x 6.48)
1. Boston-New York City	188	1,830	5,618	11,858
2. Los Angeles-San Francisco	347	2,830	8,688	18,338
3. Washington, D.C.-New York	205	1,457	4,473	9,441
4. New York-Detroit	480	615	1,888	3,985
5. Las Vegas-Los Angeles	228	608	1,867	3,940
6. New York-Pittsburgh	315	496	1,523	3,214
7. New York-Cleveland	404	493	1,514	3,195
8. Chicago-Detroit	237	392	1,203	2,540
9. Buffalo-New York	291	390	1,197	2,527
10. Minneapolis-Chicago	351	390	1,197	2,527
11. Boston-Washington, D.C.	393	374	1,148	2,424
12. Cleveland-Chicago	307	286	878	1,853
13. St. Louis-Chicago	261	283	869	1,834
14. Rochester-New York	249	262	804	1,698
15. Syracuse-New York	193	259	795	1,678
16. Phoenix-Los Angeles	356	259	795	1,678
17. Boston-Philadelphia	270	244	749	1,581
18. Dallas-Houston	225	236	725	1,529
19. Sacramento-Los Angeles	361	229	703	1,484
20. Pittsburgh-Chicago	409	206	632	1,335
21. Kansas City-Chicago	412	206	632	1,335
22. Pittsburgh-Philadelphia	257	203	623	1,315
23. San Diego-Los Angeles	111	363	1,114	2,352
24. Miami-Tampa	205	193	593	1,251
25. Reno-San Francisco	185	177	543	1,147
26. Providence, R.I.-New York	153	176	540	1,140
27. Baltimore-New York	171	171	525	1,108
28. Hartford-New York	106	168	516	1,089
29. Portland, O.-Seattle	145	161	494	1,043
30. Columbus, O.-New York	477	159	488	1,030
31. New Orleans-Houston	317	155	476	1,004
32. Indianapolis-Chicago	164	150	461	972
33. Detroit-Washington, D.C.	395	148	454	959
34. Philadelphia-Washington, D.C.	122	147	451	953
35. Cincinnati-Chicago	252	144	442	933
36. Philadelphia-Detroit	442	137	421	888
37. Las Vegas-San Francisco	416	134	411	868
38. Albany-New York	[illegible]	132	405	855
39. Kansas City-St. Louis	237	128	393	829
40. Pittsburgh-Washington, D.C.	192	126	[illegible]	816
41. New York-Philadelphia	82	119	365	771
42. Cleveland-Philadelphia	356	116	356	752
43. Chicago-Columbus, O.	275	115	353	741

CITY PAIR	DISTANCE (ST.MI.)	NO. OF PASSENGERS OUTBOUND + INBOUND (000) 1965	1975 (x 3.07)	1985 (x 6.48)
44. Norfolk-Washington, D.C.	146	[illegible]	344	[illegible]
45. Norfolk-New York	[illegible]	[illegible]	328	693
46. San Antonio-Dallas	[illegible]	[illegible]	[illegible]	[illegible]
47. Spokane-Seattle	[illegible]	[illegible]	[illegible]	[illegible]
48. Louisville-Chicago	[illegible]	[illegible]	316	[illegible]
49. Cleveland-Washington, D.C.	[illegible]	[illegible]	[illegible]	648
50. Dayton-Chicago	[illegible]	[illegible]	[illegible]	[illegible]
51. San Bernardino-San Francisco	[illegible]	[illegible]	[illegible]	[illegible]
52. Omaha-Chicago	[illegible]	[illegible]	[illegible]	564
53. Greensboro-New York	[illegible]	[illegible]	[illegible]	564
54. Dallas-New Orleans	442	[illegible]	264	[illegible]
55. Detroit-Pittsburgh	[illegible]	[illegible]	[illegible]	551
56. Detroit-Milwaukee	251	[illegible]	[illegible]	544
57. Jacksonville-Miami	[illegible]	[illegible]	[illegible]	[illegible]
58. Richmond-New York	288	[illegible]	[illegible]	531
59. Raleigh-New York	[illegible]	[illegible]	[illegible]	[illegible]
60. Buffalo-Chicago	[illegible]	[illegible]	[illegible]	[illegible]
61. Des Moines-Chicago	[illegible]	[illegible]	[illegible]	[illegible]
62. Detroit-Cleveland	[illegible]	[illegible]	[illegible]	[illegible]
63. Jacksonville-Atlanta	285	[illegible]	[illegible]	505
64. Milwaukee-Minneapolis	[illegible]	[illegible]	[illegible]	492
65. Dallas-Oklahoma City	[illegible]	[illegible]	[illegible]	[illegible]
66. Baltimore-Boston	[illegible]	74	[illegible]	[illegible]
67. San Diego-San Francisco	[illegible]	[illegible]	[illegible]	[illegible]
68. Pittsburgh-Boston	[illegible]	[illegible]	[illegible]	[illegible]
69. Tucson-Los Angeles	[illegible]	[illegible]	[illegible]	[illegible]
70. San Antonio-Houston	[illegible]	[illegible]	[illegible]	454
71. Denver-Salt Lake City	[illegible]	[illegible]	[illegible]	434
72. Memphis-Chicago	[illegible]	[illegible]	[illegible]	[illegible]
73. Detroit-St. Louis	[illegible]	[illegible]	[illegible]	[illegible]
74. Atlanta-Tampa	[illegible]	[illegible]	[illegible]	434
75. Atlanta-Birmingham	[illegible]	[illegible]	[illegible]	[illegible]
76. Dallas-Austin	[illegible]	[illegible]	[illegible]	[illegible]
77. Atlanta-Charlotte	[illegible]	[illegible]	[illegible]	[illegible]
78. Hartford-Washington, D.C.	[illegible]	[illegible]	[illegible]	[illegible]
79. Dallas-Lubbock	[illegible]	[illegible]	[illegible]	[illegible]
80. Detroit-Indianapolis	[illegible]	[illegible]	[illegible]	[illegible]
81. Utica-New York	[illegible]	[illegible]	[illegible]	[illegible]
82. Fresno-San Francisco	[illegible]	[illegible]	[illegible]	[illegible]
83. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
84. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
85. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
86. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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rate of traffic growth at the shorter distances. To check this effect, we have examined the past rate of traffic growth as a function of distance over a period of time when fares were being increased proportionally more at shorter distances than at longer distances. From 1959 to 1967, coach fares at the zero distance intercept were increased about 100 percent while they were increased about 32 percent at 500 miles (Figure 5). A regression through the ratios of 1965/1960 traffic for the top ranking 86 city pairs versus distance showed a ratio of 1.51 at the zero distance intercept and 1.84 at 500 miles, with the simple average previously noted of 1.70. These results confirm our belief that the traffic growth rate will continue to be higher at the longer distances as the zero distance fare intercept is raised. However, the additional effort involved in allowing for this effect in our calculations does not seem warranted, since the lower-than-average growth rate of city pairs at the shorter distances should be approximately balanced by the higher-than-average growth rate at the longer distances, so that the method of ratioing up city-pair traffic in proportion to the growth in total domestic traffic should yield valid total demand results.

The possibility of predicting air travel by city pair by means of a mathematical model relating air travel to intercity distance, populations, incomes, etc. was explored but abandoned in favor of the approach outlined above. The mathematical model produced rather poor correlation with actual travel because there are evidently many factors not readily quantifiable which affect travel between two cities. For example, Table 2 shows air traffic between San Francisco and two other cities. The distance to each of the other cities is about the same. The 1960 SMSA populations of Las Vegas and Eugene were 127,016 and 162,890 respectively. Based on distances and populations (the two most generally used determinants of travel), one would expect a somewhat higher volume of traffic between San Francisco and Eugene than between San Francisco and Las Vegas. The actual traffic figures of Table 2 indicate that Las Vegas must possess other virtues which increase its attractiveness to San Franciscans. It

was concluded that all factors affecting travel are already reflected in present air traffic volumes and that they represent the best basis on which to predict 1975 and 1985 traffic.

Table 2

AIR TRAFFIC BETWEEN SAN FRANCISCO AND TWO OTHER CITIES

City Pair	Air Distance	1965 OD Passengers
San Francisco-Las Vegas, Nev.	416	133,550
San Francisco-Eugene, Oregon	435	22,500

It is believed that the city pairs under 500 miles with the largest volumes of conventional air travel represent the most promising city pairs for VTOL air service for several reasons:

(1) In general these cities are the largest--and therefore present the most serious problems of access to conventional airports. The airports tend to be further out in these cities and the ground travel to the airports through heavy traffic is slower.

(2) These city pairs will generate sufficient VTOL traffic volume to provide a suitable frequency of VTOL service.

(3) These cities will generate sufficient VTOL passenger volume to justify the required investment in vertiports.

In this study, we have not attempted to develop route schedules linking different city pairs together. Our analysis is based on simple shuttle operations by individual city pair. Obviously, the different city pairs would be organized into route networks and individual VTOL aircraft would be scheduled over the networks, much as today's conventional aircraft are scheduled.

4

BREAKDOWN OF CITY-PAIR AIR TRAFFIC BY SEGMENT PAIR

Appendix B describes the method by which local (intracity) origins and destinations (OD's) of passengers were related to radial distance from the center of the city. Because the local OD's are a function of the distance from the city center, a method of segmenting the city by rings centered on the central business district (CBD) was developed. Figure 4 shows Dallas and Houston as a sample city pair. In this particular case, both cities were segmented into a central core plus three rings. Each of the outer rings was divided into quadrants by the north-south and east-west axes, resulting in 13 segments for each city. For Dallas and Houston a total of 13 x 13 = 169 segment pairs result.

For each city the following data were developed:

(1) The radius from the city center to each of the circles. Depending on city size, from two to six circles were used.

(2) The percentage of each segment inhabited. This is especially important for cities located on large bodies of water where the pattern of passenger OD's is greatly altered by local geography.

(3) Straight-line distances to the nearest CTOL airport and to the city-center vertiport, including a notation stating whether the trip involves travel through heavy city traffic areas.

These basic inputs, together with the distribution of local OD's versus radius (Appendix B), and the ground times and costs versus distance (Appendix C) permit the breakdown of total traffic into segment-pair traffic and the calculation of ground travel times and costs by segment pair. Section 10 illustrates the sample calculations for Dallas-Houston.

The segments used in this study for any city can be reproduced as follows:

(1) The center of the rings is located at the vertiport (see maps, Appendix L).

(2) The ring radii in statute miles are given in the input data sheets of Volume III under "In Rad" and "Out Rad." The four segments per ring are determined by the north-south and east-west axes through the vertiport location and are numbered starting with the northeast segment (see Figure 4). The percent inhabited for each segment is given, to the nearest 10 percent, under the "Per Inhab" column of the input data sheets.

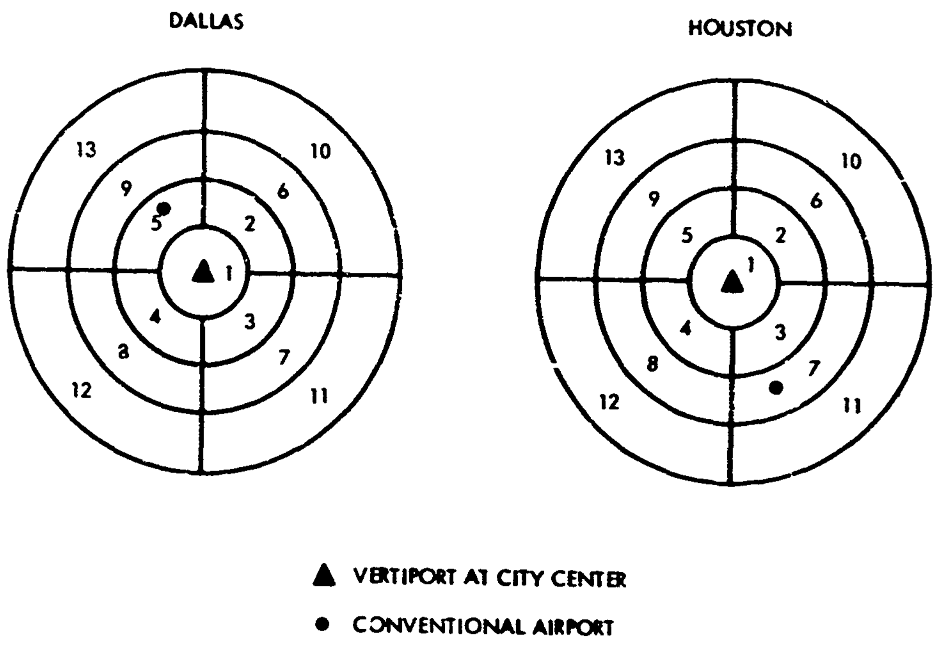

FIGURE 4. Passenger Local Origin and Destination Segments for Dallas and Houston

5
AIRCRAFT COSTS

Our analysis requires aircraft operating costs as an element of the airline fare required to earn a given return-on-investment. These costs are necessary inputs to the demand analysis.

Aircraft manufacturing costs and costs for research and development are required as the essential determinants of the supply schedule.

5.1 AIRCRAFT OPERATING COSTS

The aircraft direct operating costs were estimated by component category. The components of direct operating cost reported by the CAB consist of (1) crew, (2) fuel, (3) maintenance, (4) insurance and (5) depreciation. Estimating relationships were developed for the first three categories. The remaining direct operating cost components--insurance and depreciation--are dependent upon an aircraft's price, and since the assumption of parametric changes in price is used to generate a demand schedule, these costs are included in the study as part of the airlines' investment which must earn a given rate of return.

Indirect operating costs consist of maintenance and depreciation costs for ground equipment as well as general service and administration expenses. One estimating relationship was derived for this entire cost category.

The general method for developing cost estimates was to attempt to relate present patterns of cost to an aircraft's performance or design characteristics. These patterns were then related to the characteristics for future VTOL aircraft as provided by the study.

5.1.1 Crew Costs

Crew costs per hour for a variety of aircraft in commercial operation demonstrate a consistent linear pattern when plotted against seat-mile productivities (no. of seats x miles per hour). Typical mission profiles for VTOL aircraft were investigated and seat-mile productivities determined. These were fitted to the present pattern of payment to yield estimates of crew costs per hour.

5.1.2 Fuel Costs

Fuel costs per hour were, likewise, determined from an examination of aircraft in commercial operation, and these costs were related to either maximum thrust rating, in the case of jet aircraft, or to maximum shaft-horsepower rating, in the case of rotor or propeller aircraft. The ratio of pounds of fuel consumed per hour per pound of thrust (or horsepower) was determined to depend upon the distance flown. This ratio was plotted for commercial aircraft, including helicopters, against the average distances flown, as reported by the CAB. The appropriate thrust rating (or horsepower)--the denominator of the ratio--was provided for the aircraft studied, and this information together with the above ratio determined the pounds of fuel consumed per hour--the numerator of the ratio--at various stage lengths. Pounds of fuel were readily translated into a dollar cost for fuel.

5.1.3 Maintenance Costs

Maintenance costs per hour (including maintenance burden) represent the cost component which has been estimated to differ most significantly from present airline experience. The approach used was to attempt to estimate helicopter maintenance costs by using existing operational experience to contrast helicopters with conventional aircraft. The other VTOL aircraft were assumed to fit the helicopter pattern. Conventional fixed-wing aircraft in commercial operation demonstrate a linear relation when plotted against aircraft empty weight. Helicopters demonstrate a similar relation, but with a significantly

increased slope. Pound for pound, helicopters are more costly to maintain. Due to the very limited experience for helicopters in commercial operation these data were augmented by military helicopter experience.

5.1.4 Indirect Operating Costs

Indirect operating costs per passenger were estimated by noting the consistent linear pattern for these costs when related to average trip distances for all airlines in scheduled domestic operation. A trend line was fitted to the data reported by the CAB for helicopter, local service, and domestic trunk airlines, and minor changes were made in the statistical fit to adjust for differences between present operations and operations on future high density intercity VTOL routes.

5.2 AIRCRAFT INVESTMENT COSTS

Aircraft manufacturer's costs were estimated from regression analyses of an aircraft's design characteristics on both recurring and nonrecurring costs for a large population of production aircraft. The fixed-wing population consisted of those aircraft included in a study of airframe costs by The Rand Corporation, in which detailed cost information was published for a variety of conventional aircraft. The basic method employed in this portion of the study was to add helicopters to this population and a single estimating relation, with the appropriate statistical properties was determined which explained costs for this wide group of apparently different aircraft types. Cost and design characteristics for the helicopters in this group were obtained from a study of helicopter costs conducted by the Department of Defense. This equation related these costs to such design characteristics as aircraft weight and thrust rating and was used to estimate VTOL recurring costs.

Unfortunately, data for nonrecurring costs were not available for helicopters, and an equation based upon a similar approach could not be determined for this category of costs. However, it was found that a similar combination of the variables of weight and

thrust used in the previous equation for recurring costs could be employed to explain the nonrecurring costs for fixed-wing aircraft. This suggested that the form of the equation had wide application, and suggested, further, that a relation existed between nonrecurring and recurring costs. This latter relation provided an alternative method for estimating nonrecurring costs.

Nonrecurring costs for helicopters were estimated from the equation based on fixed-wing data only, and these were compared with the estimates obtained by using the relation found between nonrecurring and recurring costs of conventional aircraft. Both equations yielded similar helicopter nonrecurring costs. This result supported the view that our equation based upon fixed-wing experience, which demonstrated a capability for estimating helicopter costs, could be used to estimate nonrecurring costs for other VTOL aircraft as well.

The recurring and nonrecurring costs for engines were estimated from equations published by The Rand Corporation.

See Appendix D for a detailed description of the cost estimates used in the study.

6

CTOL AND VTOL TRIP TIMES AND COSTS

6.1 TRIP TIMES

The CTOL and VTOL trip times between segment pairs of a city pair are the sum of the following:

(1) Ground time from the segment of the origin city to the airport or vertiport.

(2) CTOL or VTOL block time between the city pair.

(3) Ground time from the airport or vertiport to the segment of the destination city.

Transfer times between ground and air modes are assumed to be the same for CTOL and VTOL. As a common transfer time cancels out in determining the difference in trip times, the study results are not sensitive to the length of the transfer time.

6.1.1 Ground Times

The ground times are determined from trends of ground times vs. straight-line distance to the airport or vertiport (Appendix C, Figure C1). Two trends are used; one if the trip involves travel through city traffic, and another for trips which do not involve travel through city traffic, from suburbs to a suburban airport on the same side of the city.

6.1.2 Block Times

Block times for the various aircraft types are presented in Appendix A, Figure A7.

6.2 TRIP COSTS

The CTOL and VTOL trip costs between segment pairs of a city pair are the sum of the following:

(1) Ground cost from the segment of the origin city to the airport or vertiport.

(2) CTOL or VTOL fare between the city pair.

(3) Ground cost from the airport or vertiport to the segment of the destination city.

6.2.1 Ground Costs

The ground costs are determined from a trend of ground cost vs. straight-line distance to the airport or vertiport (Appendix C, Figure C3).

6.2.2 CTOL Fares

CTOL fare as a function of distance was calculated by the method described in Appendix H and is shown as the "1968 Calculated" line in Figure 5. The fare was based on the costs for the Boeing 727 presented in Appendix D and represents a weighted average of first class and coach fares. A flyaway price of $4.8 million was used. The seat costs for the DC-9 were estimated to be nearly the same as for the 727; therefore the "1968 Calculated" line represents what the fare structure for present jet aircraft should be to earn the target rate of return as described in Appendix E. The 727 design range is about 2000 st. mi.; as a result, its empty weight is 86,000 pounds, which is greater than the empty weight of any 95-seat VTOL aircraft, all of which have much lower design ranges (Figures A1 to A6). If a 95-seat CTOL airplane were designed for the same range as the VTOL's, its weight would be about half that of the 727 and the fares for ranges up to 500 miles would be much less.

Although the longer design range permits greater scheduling flexibility, airplanes with a lower design range than that of the 727 will probably be developed, and such aircraft would have significantly lower fares than that of the 727 on stage lengths up to 500 miles. If such a plane were developed, the competitive standing of the VTOL aircraft would be worse than indicated in this study.

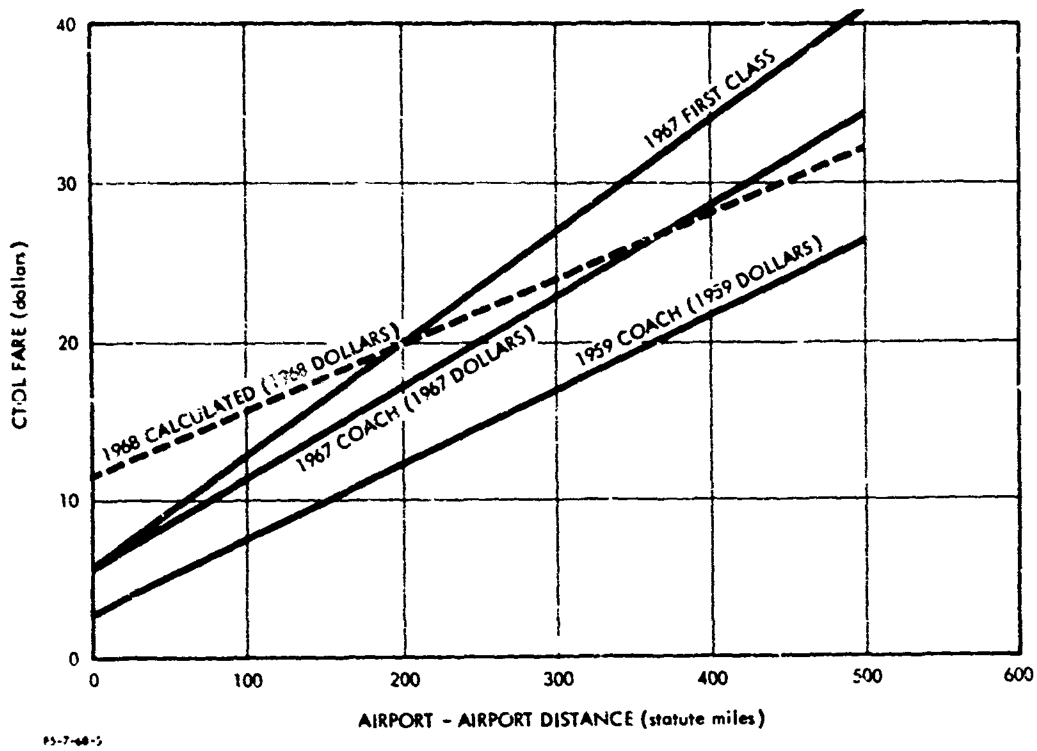

FIGURE 5. CTOL Fares (Includes 5% Federal Tax)

Actual 1967 coach and first class fares are also shown on Figure 5. These lines were developed by fitting lines through published fares for service between large city pairs less than 500 miles apart. As can be seen, the present fares are too low to permit the desired return on investment at ranges less than 300 miles. Experts agree that long-haul profits subsidize short-haul losses. The president of Eastern Airlines recently wrote:[1]

1. "The New Economics of the Airline Industry," by Arthur D. Lewis, Astronautics and Aeronautics, November 1967.

> ... we must revise our fare structure so that short-haul fares more closely reflect the cost of short-haul operations. This will relieve our long-haul passengers from the burden of subsidizing short-haul services and free the industry to perform its traditional vital role: Generating and carrying longer-haul traffic . . .
>
> Until now, the primary factor that has limited the degree of industry interest in the STOL airplane is the obvious financial loss the airlines would incur with it under the present short-haul fare structure. Thus, it seems to me that the first and most essential step in developing STOL capability is to recognize the true expense of short-haul operations by conventional airplanes.

The latter statement is equally applicable to the VTOL aircraft considered here.

Comparison of the 1959 and 1967 coach fares on Figure 5 indicates that underpricing of the short-haul routes is being corrected. Over these eight years, the zero-distance fare intercept has been doubled. If it is doubled again, the fare structure would then be such that a reasonable return on investment from short-haul operations would be realized. The equation for the "1968 Calculated" CTOL fare (in 1968 dollars) including 5 percent tax is:

$$\text{CTOL Fare} = 11.57 + .048\ (\text{DIST.}) - .0000126\ (\text{DIST.})^2$$

In spite of increasing labor costs, the airline industry has been able to hold seat-mile costs fairly constant over the last two decades through the introduction of larger and more efficient aircraft. It is assumed that this trend will continue and that the "1968 Calculated" CTOL fare of Figure 5 will remain valid (in 1968 dollars) throughout the time period of the study.

6.2.3 VTOL Fares

VTOL fares as a function of distance were calculated by the method described in Appendix H. Regression equations were then fitted through the calculated fare points. These equations are presented in Table 3 for different prices for each of the six VTOL aircraft types. For the fan or jet lift type, fares were calculated for 30, 60, 90, 120 and 150 seat sizes. For the other five types, fares were calculated

Table 3

VTOL FARE EQUATIONS AS A FUNCTION OF DISTANCE

$$\text{Fare } \$ = A + B\,(\text{Distance}) + C\,(\text{Distance})^2$$

Seats	Price ($ Million)	A	B	C
		Conventional Helicopter		
90	2	6.88	.0985	-.0000174
	4	7.43	.1080	-.0000256
	6	7.98	.1275	-.0000337
	8	8.52	.1470	-.0000419
	10	9.07	.1665	-.0000500
	12	9.62	.1860	-.0000582
		Compound Helicopter		
90	3	5.26	.0915	-.0000263
	5	9.02	.1073	-.0000355
	8	10.15	.1311	-.0000493
	11	11.29	.1548	-.0000631
	14	12.42	.1786	-.0000769
		Tilt Rotor		
90	4	8.65	.0807	-.0000328
	6	9.36	.0932	-.0000408
	9	10.41	.1118	-.0000528
	12	11.46	.1305	-.0000648
	16	12.87	.1554	-.0000808
		Tilt Wing		
90	6	9.41	.0857	-.0000377
	8	10.10	.0968	-.0000448
	10	10.79	.1029	-.0000519
	12	11.48	.1191	-.0000590
	16	12.85	.1413	-.0000731
	20	14.23	.1635	-.0000873

Seats	Price ($ Million)	A	B	C
		Stowed Rotor		
90	6	9.52	.0851	-.0000354
	8	10.21	.0959	-.0000423
	10	10.89	.1067	-.0000492
	12	11.58	.1176	-.0000561
	15	12.61	.1338	-.0000664
	20	14.32	.1609	-.0000836
		Fan or Jet Lift		
30	4	13.72	.1304	-.0000570
	6	15.75	.1595	-.0000751
	8	17.78	.1887	-.0000930
	12	21.82	.2471	-.0001292
	15	24.86	.2909	-.0001564
60	5	11.15	.0929	-.0000408
	8	12.67	.1148	-.0000543
	10	13.67	.1294	-.0000634
	14	15.70	.1586	-.0000814
	18	17.73	.1877	-.0000994
90	7	10.65	.0852	-.0000386
	10	11.66	.0998	-.0000476
	12	12.34	.1095	-.0000536
	15	13.35	.1241	-.0000627
	20	15.04	.1485	-.0000777
120	10	10.67	.0849	-.0000394
	12	11.18	.0922	-.0000438
	15	11.94	.1031	-.0000507
	20	13.20	.1214	-.0000621
150	12	10.36	.0834	-.0000398
	15	10.97	.0922	-.0000453
	20	11.98	.1067	-.0000543
	25	12.99	.1213	-.0000634

only for the 90 seat size. In each case, the fares are based on the weight and performance characteristics as shown in Appendix A, Figures A1 through A6. Fares are also presented graphically for the 90 seat size of each type of VTOL aircraft (Figures 6 through 11).

Based on the fare structure for each price, the demand can be determined for each aircraft type as a function of price.

6.2.4 <u>Future CTOL and VTOL Fares</u>

It is possible that future CTOL and VTOL fares might be significantly reduced by technological or operational innovations. For example, boron filament structures, improved engine specific fuel consumption or specific weight, etc. could significantly reduce aircraft direct operating costs. Similarly, no-reservation shuttle operations, computerized ticketing, etc. could markedly reduce indirect operating costs. However, in both cases, these innovations should be equally applicable to both CTOL and VTOL aircraft. Accordingly, the fare reductions for both CTOL and VTOL aircraft in intercity competition should be approximately the same and the difference between CTOL and VTOL fares should remain approximately as shown in this study. Since our method of analysis depends primarily on the difference between CTOL and VTOL fares, these innovations should have little effect on the results of the study.

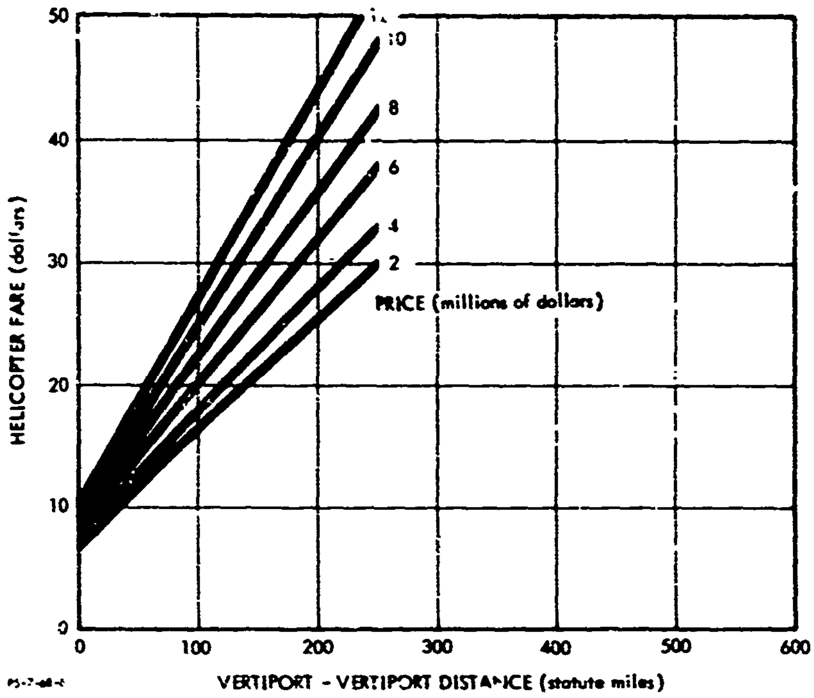

FIGURE 6. 90 Seat Helicopter Fares (Includes 5% Federal Tax)

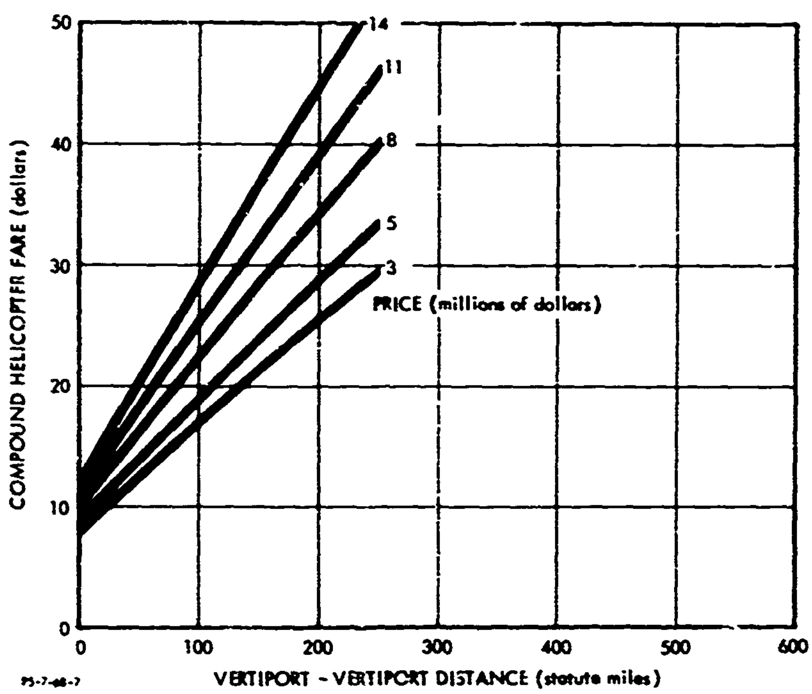

FIGURE 7. 90 Seat Compound Helicopter Fares (Includes 5% Federal Tax)

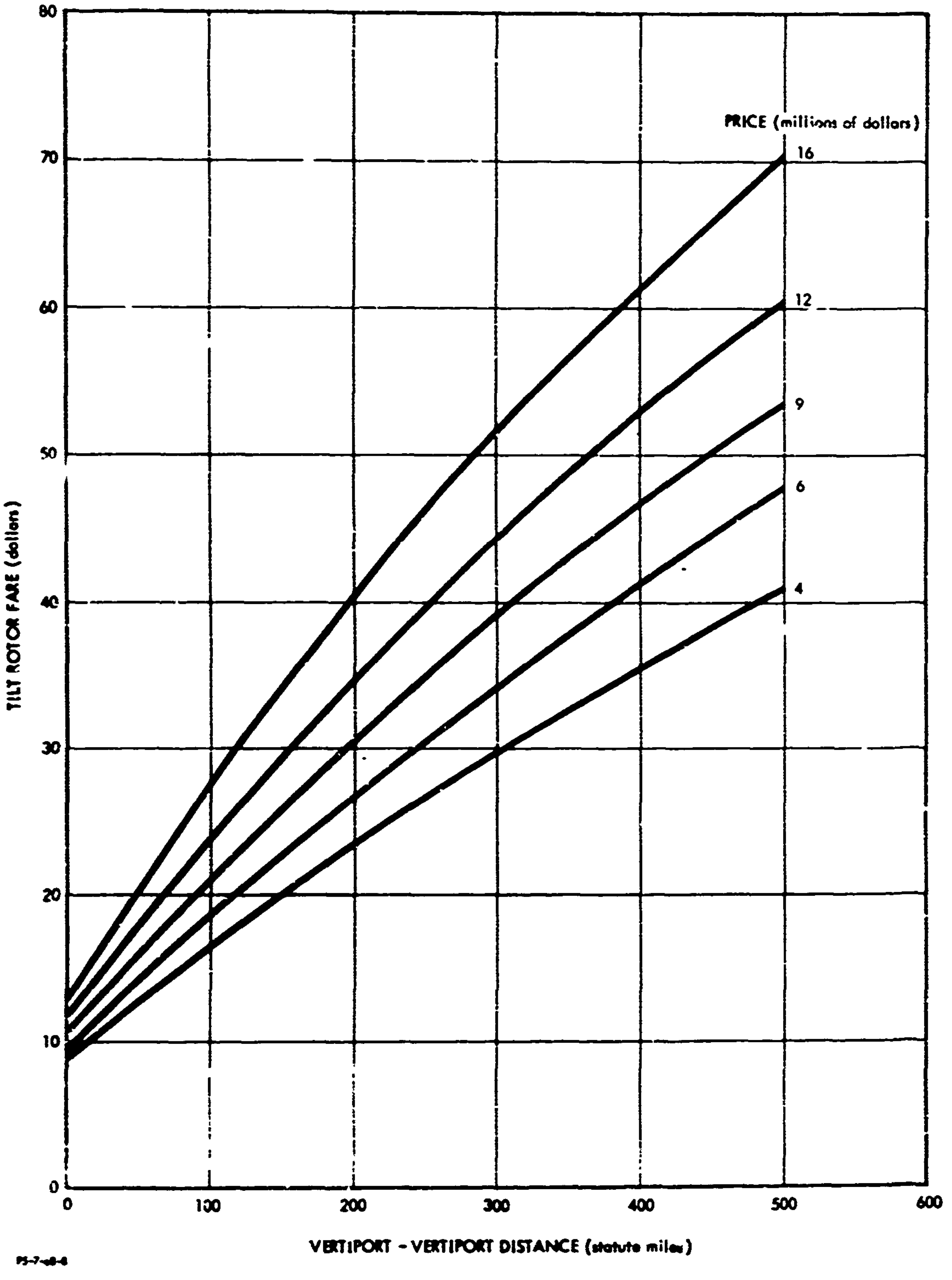

FIGURE 8. 90 Seat Tilt Rotor Fares (Includes 5% Federal Tax)

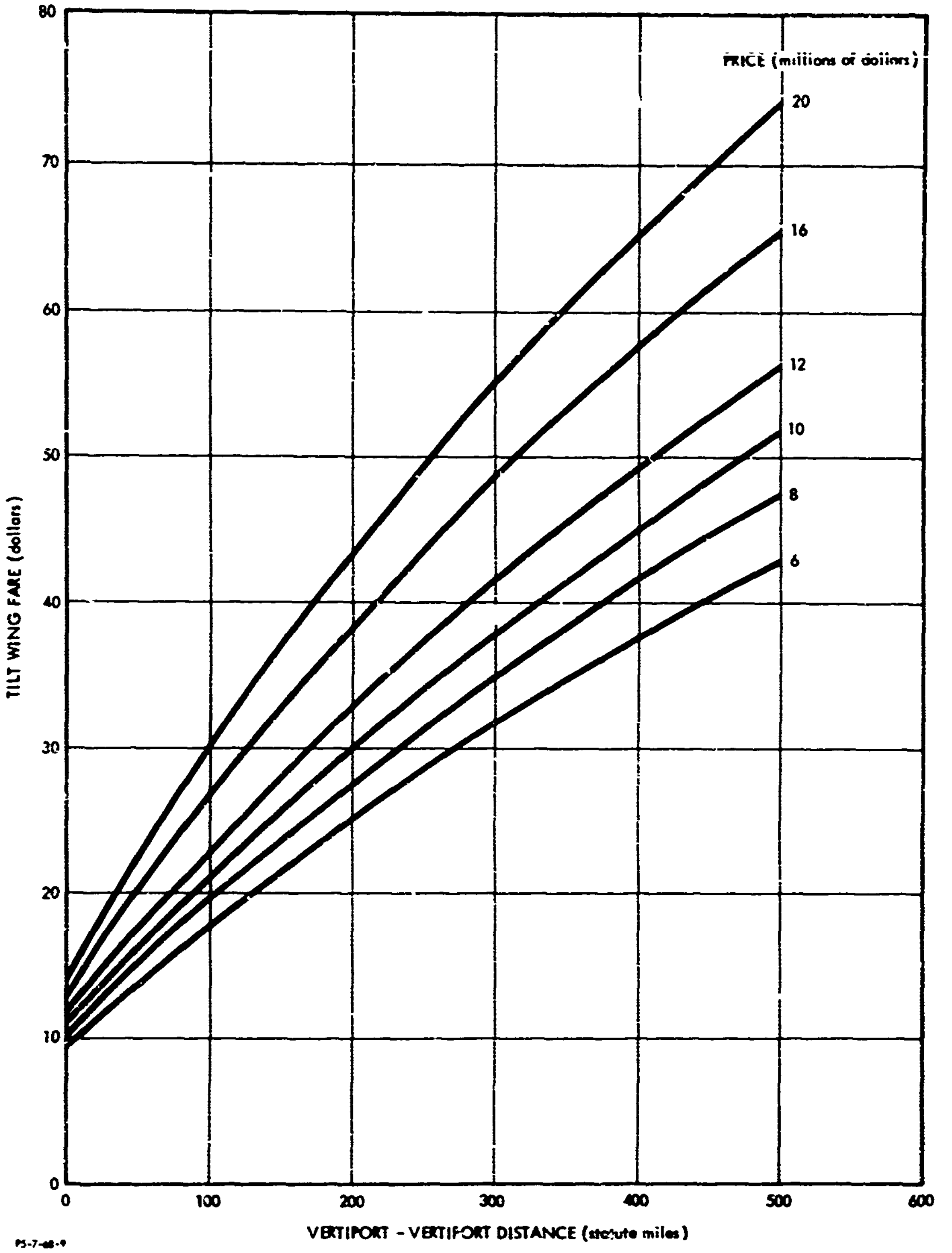

FIGURE 9. 90 Seat Tilt Wing Fares (Includes 5% Federal Tax)

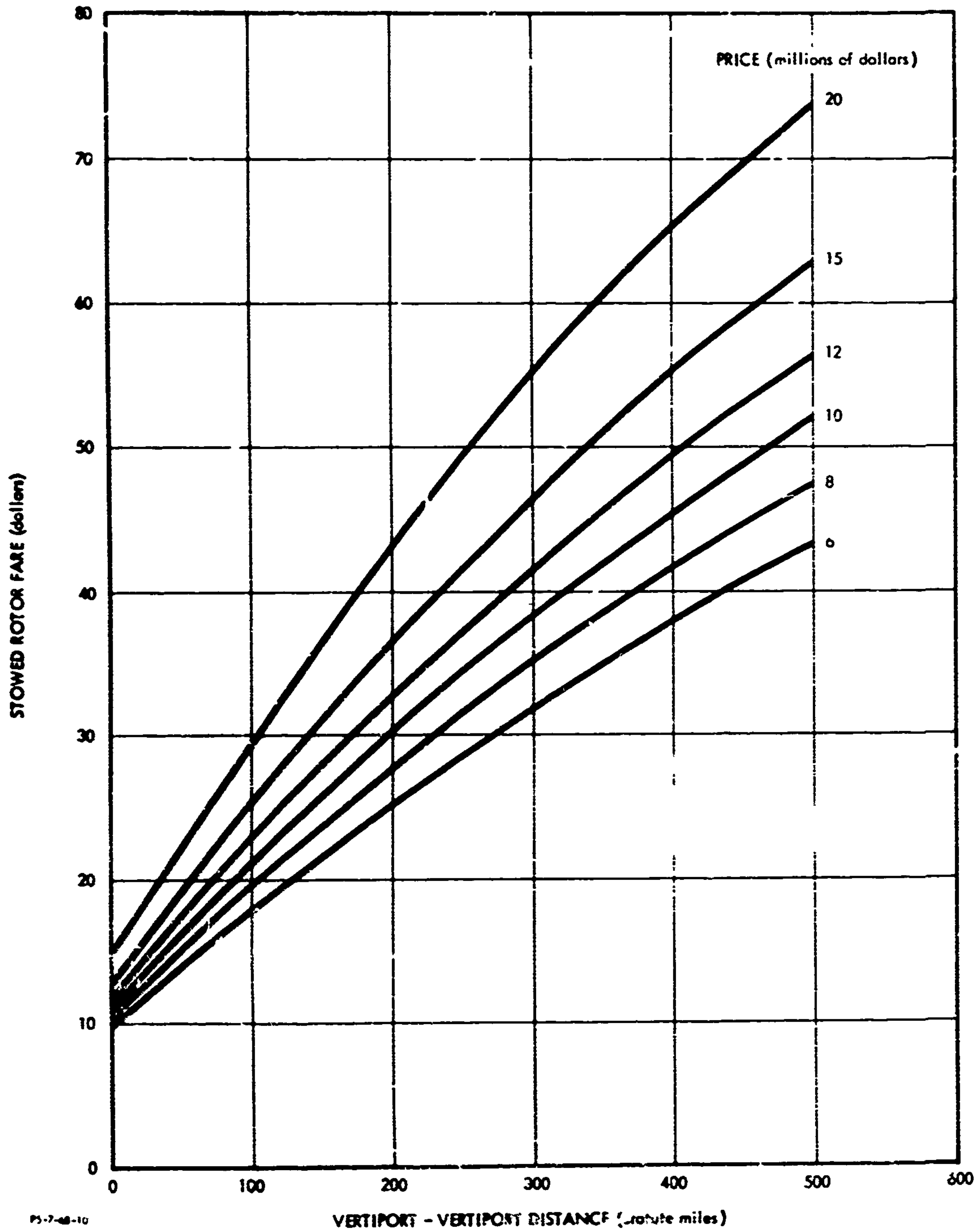

FIGURE 10. 90 Seat Stowed Rotor Fares (Includes 5% Tax)

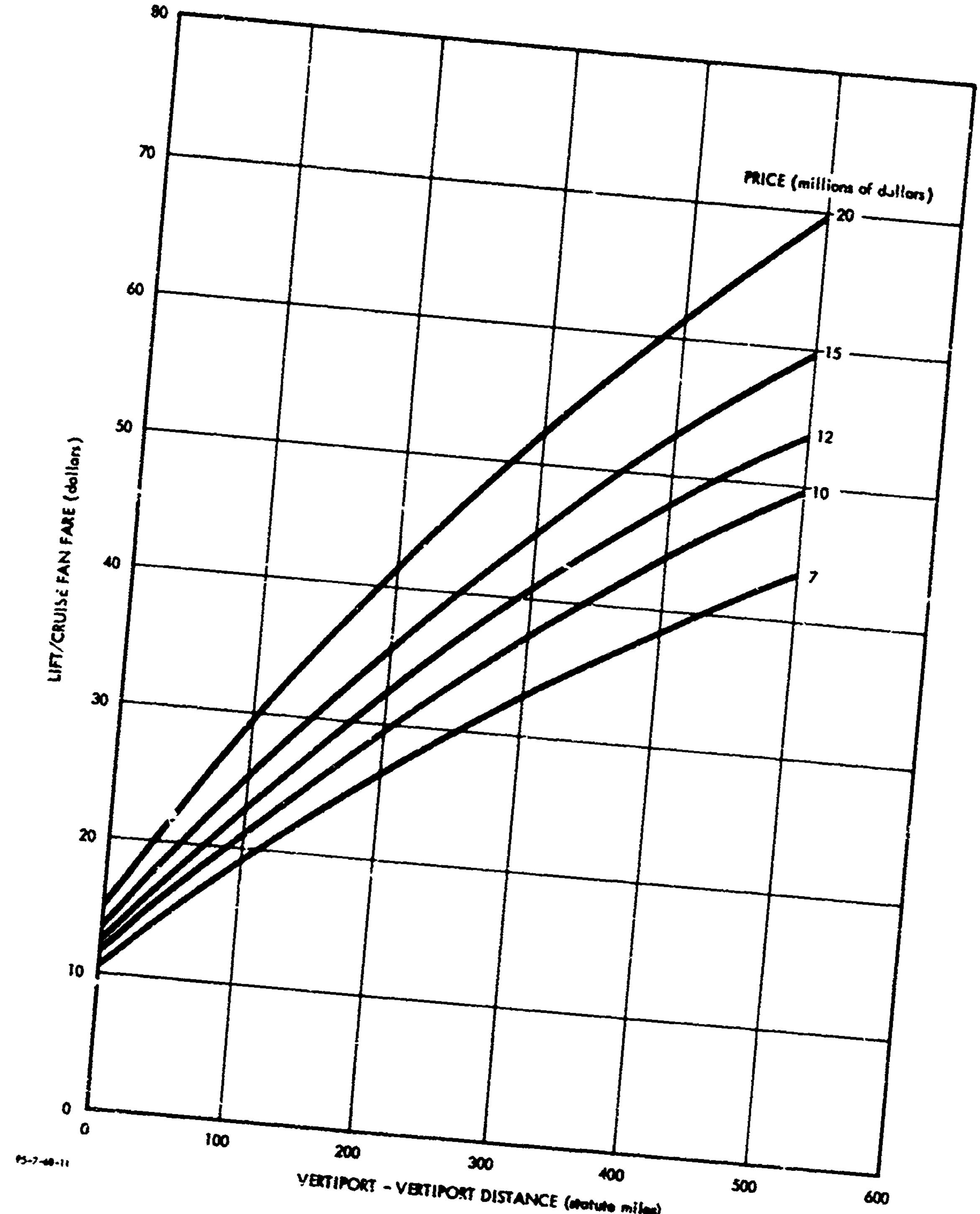

FIGURE 11. 90 Seat Fan or Jet Lift Fares (Includes 5% Federal Tax)

7

SPLITTING PASSENGER DEMAND BETWEEN CTOL AND VTOL

The value that passengers place on their time must be estimated in order to split passenger demand between a faster, more expensive service and a slower, cheaper service. In this study the VTOL service will be faster but more expensive than CTOL for travelers between the great majority of segment pairs. From the relative trip times and costs, one can determine the cost of saving time by VTOL. For example, if the VTOL service saves 0.5 hour but costs \$3.00 more than CTOL, between a particular segment pair, the cost of saving time by VTOL would be \$3.00 ÷ .5 = \$6.00 per hour. One must then determine what percent of the passengers value their time at \$6.00 per hour or more in order to split the total passenger demand between VTOL and CTOL.

A recent IDA study involving passenger demand for supersonic transport service encountered this value of time problem.[1] In that study the passenger choice was between subsonic and supersonic jet service. Details of the value of time analysis are included in the IDA supersonic transport report and are summarized below.

Economic theory suggests that travelers would value their time as a function of their earning rate. Accordingly, income distribution of air passengers was obtained from a number of surveys conducted by various airlines, the Survey Research Center of the University of Michigan, and the Port of New York Authority. These surveys recorded family income. Based on the ratio of earned to unearned income at various income levels, the distribution was reduced from the total income reported in the surveys to earned income. Because earnings

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1. Institute for Defense Analyses Report R-118, Demand Analysis for Air Travel by Supersonic Transport, December 1966. Available from: Federal Clearing House for Scientific and Technical Information, U.S. Department of Commerce, Springfield, Virginia, 22151.

tend to increase over time, a rate of increase in real per capita income of 2.5 percent per year was used to increase these earnings distributions in future time periods (Figure 12). Based on 2000 hours worked per year, the annual earnings can be converted to earnings per hour as shown on Figure 12. For example, a person earning $10,000 per year would be considered to have an earning rate of $5 per hour and if he valued his time at his earnings rate, he would value his travel time at approximately $5 per hour.

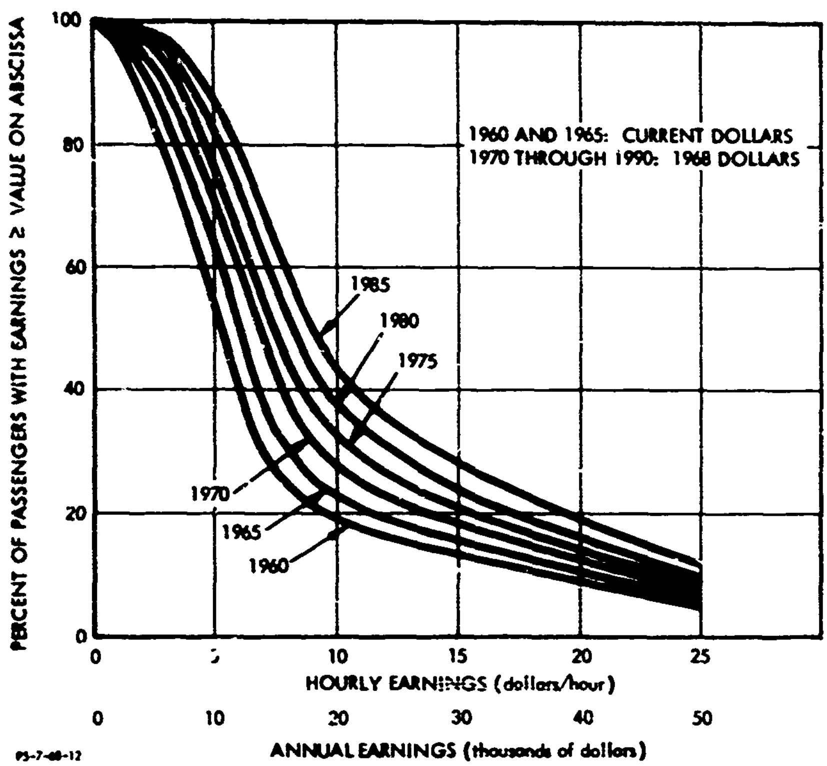

FIGURE 12. Earnings Distribution of Air Passengers, U.S. Domestic Routes

The hypothesis that the average traveler would value his time at his earnings rate was tested by the four methods discussed below:

(1) Elasticities of total demand to trip fare and time changes were developed. By comparison of these elasticities an average value of time could be inferred. For example, if a decrease in trip time of one hour increased the number of trips by the same amount as a $5 reduction in fare, then it could be deduced that in this particular case passengers in the aggregate tended to value their time at approximately $5 per hour. This method was used with both domestic and North Atlantic traffic data. In the case of domestic traffic the average value of time obtained was very close to the

average earning rate for the time period studied. However, in the case of the North Atlantic the value of time indicated by this method was nearly double the average earning rate.

(2) During the introductory period of the jets, a jet surcharge was added to the regular propeller fares both on domestic and on North Atlantic routes. A cost of saving time was obtained by dividing this surcharge by the jet time saving. Comparison of the percent of passengers selecting jet with the passenger earnings distribution yielded an estimate of how passengers value their time relative to their earnings. In the case of domestic passengers the split between jet and piston service was close to the split predicted by the value-of-time equal to earnings-rate hypthesis. However, in the case of North Atlantic passengers, points were obtained indicating that passengers were willing to pay between 1.3 and 2.1 times their earning rate. The basic results here and those obtained under (1) above were parallel. In the North Atlantic case it is believed that the jet passengers were willing to pay more in order to reduce the fatigue of the approximately 12-hour piston flight. Therefore, the amount paid by the passengers exceeded the amount which they would be willing to pay for pure time saving. Our study considers routes up to only 500 miles, so that this fatigue factor should be negligible, and the domestic situation discussed above should be the more applicable case.

(3) A comparison of the split of passenger demand between ground common-carriers and air was made. This analysis is superceded by the analysis presented in Appendix J of this report which is based on a more comprehensive set of data. The percent of common-carrier passengers going by air versus cost of saving time by air was determined (the cost of saving time by air decreases with trip distance and the percent of passengers going by air increases with trip distance). This distribution shows how much passengers are willing to pay to save time in intercity travel. This distribution was then compared with the distribution of passenger earning rate to determine how passengers value travel time relative to their earning rate. The analysis of Appendix J indicates that travelers value their time at approximately .65 times earnings.

(4) Both domestic and foreign airlines were asked for their views on how passenger demand would split between faster, more expensive supersonic service and slower, less expensive subsonic service. Twelve curves were obtained from ten different airlines (two airlines submitted both domestic and international curves).[2] The curves of seven out of the

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2. Op. cit., IDA Report R-118, II, pp. 54-56.

ten airlines agreed quite well with the IDA curve. The other three were substantially higher. The resulting airline consensus, based on a simple average of all airline curves was that travelers value their time at approximately 1.5 times earnings. In all cases, the airlines said that their curves were based on subjective judgment, not quantitative analysis.

The subject of how passengers value their time is an extremely complicated one. Certainly, individuals with identical earnings will value their time differently; indeed, the same person will value his time differently depending upon the urgency of his trip and the particular schedule involved. Further, there is a widespread belief, which we have been unable to verify analytically, that business travelers value their time at a higher rate relative to their earnings than nonbusiness travelers. An additional complicating factor is that surveys record family income, but the principal earner will probably value his time at a different rate than his dependents. Recognizing these complicating factors, it is apparent that no precise answer to this problem is possible. The four methods of checking outlined above, however, indicate that the initial hypothesis (that travelers, in the aggregate, value their time at their earning rate) should provide reasonably accurate results.

Figure 13 indicates the effect on demand at various hourly earnings if passengers value their time at about 2/3 earnings rate (as indicated by Appendix J) instead of at 1 x earnings rate as used in calculating the results of this study. Because of the shape of the earnings distribution curve, the effect is quite small up to about \$3 hr. but becomes quite large above \$5 hr. Accordingly, for the most competitive VTOL aircraft the loss in demand would be smaller than for the less competitive types. Roughly speaking, the demand for the four fastest VTOL types would be about 75 percent the demand shown if passengers value their time at 2/3 earnings rate instead of at 1 x earnings rate. For the helicopter and compound helicopter, the demand would be about 62 percent of that shown.

The results of the study are based on the demand for 1985--the estimated final year of the aircraft production program. The percentage passenger demand for the faster, more expensive mode will be lower

in 1975 than in 1985 because of the lower earnings distribution. Assuming passengers value their time at their earnings rate, Figure 14 shows, at various hourly earnings, the ratios of passengers preferring the faster, more expensive mode in 1975 relative to 1985. Due to the shapes of the earnings distribution curves, the ratios are high up to about \$5 hr. and then drop to about 74 percent above \$8 hr. and remain fairly constant at that percentage on up to \$25 hr. Accordingly, the 1975 percentage passenger preference for the most competitive VTOL aircraft would be roughly 85 percent of the 1985 level; however, for the less competitive types, where passengers would have to pay \$8 or more per hour to save time, the 1975 preference would be only about 74 percent of the corresponding 1985 figures.

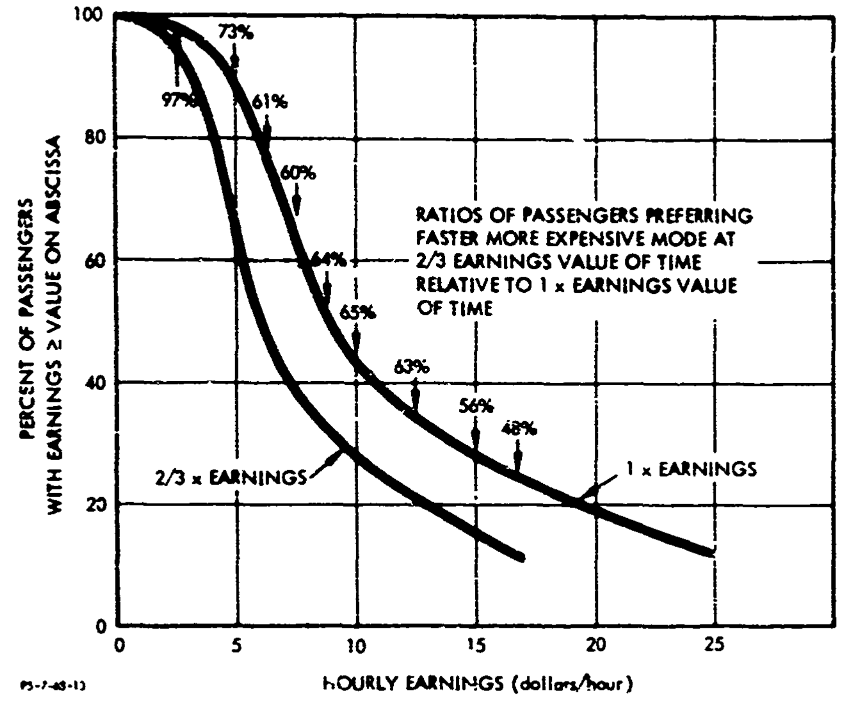

FIGURE 13. Split in Passenger Demand for Value of Time = 2/3 Earnings Rate Relative to Split for Value of Time = 1 x Earnings Rate 1985

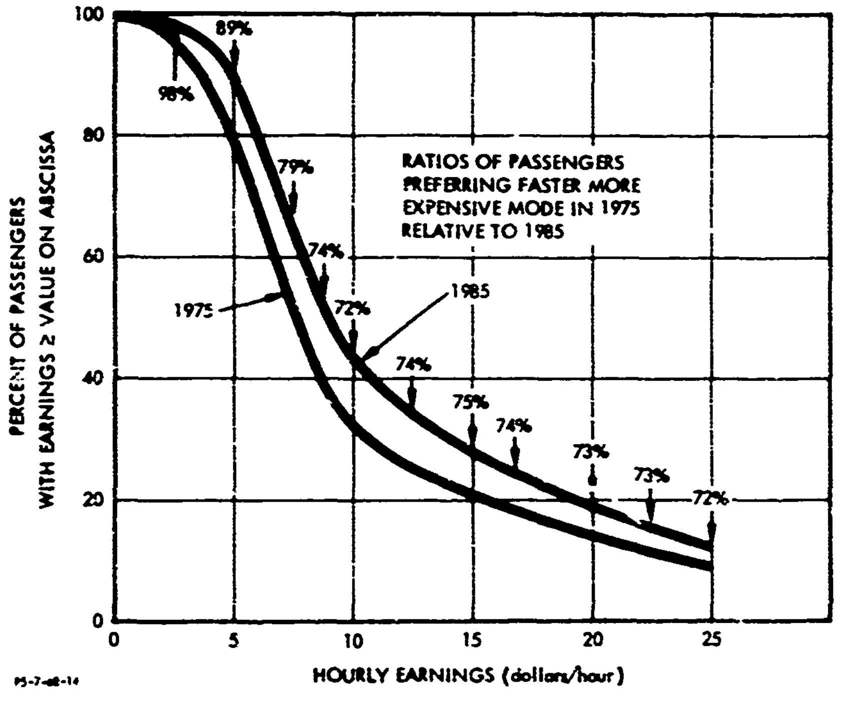

FIGURE 14. Split in Passenger Demand for Value of Time = 1 x Earnings Rate for 1975 and 1985

8

STIMULATION OF AIR TRAVEL BY VTOL

We can expect VTOL not only to capture some of the CTOL market, but also to increase the total amount of air travel because of the time saving of VTOL over CTOL. This increase is derived from two sources: a shift from ground modes of travel to VTOL travel, and an increase in the average number of trips by former CTOL passengers who switch to VTOL.

In order to determine the extent of this stimulation of air travel, we have relied on the implications suggested by a number of empirical relationships observed in the travel market. In Appendix K three methods have been used to determine the extent of this stimulation and to serve as cross checks on each other. One method is based on the relationship between trip distance and the percent of passengers taking the air mode; a second method is constructed on a statistical relationship between the number of air trips, trip time, and other independent variables, and a third method is based on the implications of the effect of the 1947 change in the location of the airport serving Detroit on air travel between Detroit and other cities.

A comparison of the results of all three methods for a 50-minute time saving is shown on Figure K5. We decided to use the Detroit Airport move as the basis for determining the effect of a 50-minute time saving because it directly reflects the effect of airport location on air travel. Utilizing the second method the equation based on the Detroit Airport move was generalized to permit calculation for any time saving. The resulting generalized equation used in calculating VTOL passenger augmentation was:

$$V = 1.15(.728T^{.450})e^{DT/(-260.9\ -104.4T)}$$

where

V = augmentation factor

T = time saved (in minutes) by VTOL over CTOL

D = distance (in miles).

The increase in the total number of passengers is given by

$$P_a = (V-1)P_s$$

where

P_a = passenger increase and

P_s = VTOL passengers after split of initial CTOL passengers between CTOL and VTOL service.

The total number of VTOL passengers after augmentation is represented by:

$$P_v = VP_s$$

where

P_v = VTOL passengers after augmentation.

The combined effects of basic CTOL traffic growth and VTOL stimulation of air travel is shown in Figure 15. The basic CTOL traffic growth is shown by the three horizontal lines representing the ratios of 1975 and 1985 CTOL traffic to the 1965 level of passengers. The two curved lines represent these ratios as a function of intercity distance after the effect of VTOL stimulation. For example, at an intercity distance of 100 miles, the 1985 total air passengers would be 16.8 times the 1965 level. These curves are based on a 50-minute total time saving per one-way trip by VTOL over CTOL and equal air fares for both. Accordingly, these curves incorporate the maximum practical VTOL stimulation effect. For the slower types of VTOL aircraft the average time saved will probably be less than 50 minutes; for all VTOL types the fares are likely to be somewhat more than the CTOL fares. If the time saved by VTOL is less than 50 minutes or if the fares are higher than CTOL fares, the degree of VTOL traffic stimulation would be reduced from that shown.

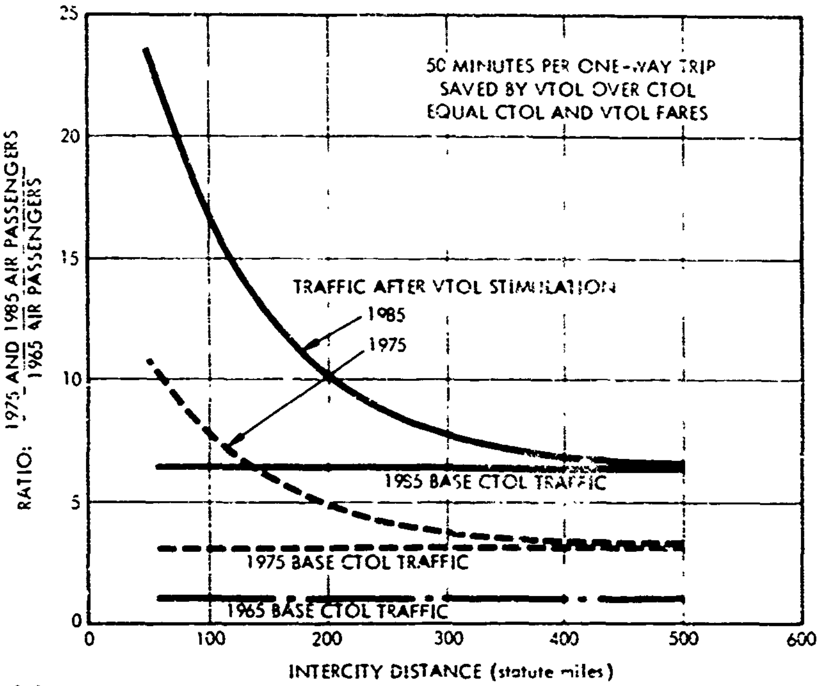

FIGURE 15. Ratios of 1975 and 1985 Air Passengers to 1965 Air Passengers Versus Distance

9

EXPORT MARKET

To establish the total market for VTOL passenger transports it is necessary to include an export quantity. A detailed analysis of the foreign market by city pair was rejected because the aircraft export market depends in large measure not on the pure economics of the situation but on various international factors such as the balance-of-payments, tariffs, subsidy of domestic aircraft industries, and political climates. Accordingly, it was decided to estimate the export market in a more generalized method. Sales of US short-haul jet aircraft were selected as being the most similar product group to the VTOL aircraft under consideration. Table 4 indicates the cumulative sales of the Boeing 727 and 737, and the Douglas DC-9 to domestic and foreign airlines as of September 1967. In accordance with the past experience indicated by this table, the total market is estimated at (1310 ÷ 955) x domestic market. This is the coefficient used in our analysis to account for foreign sales.

Table 4

EXPORT MARKET FOR SHORT-HAUL JET AIRCRAFT

Aircraft	Sales to Domestic Airlines	Sales to Foreign Airlines	Total Sales
Boeing 727	535	109	644
Boeing 737	130	59	189
Douglas DC-9	290	187	477
Total	955	355	1310

SAMPLE CALCULATION

The tremendous volume of calculations required the use of a computer to generate the results of the study. Since the method of analysis has been explained in the previous sections of the report, only a sample hand calculation for Dallas-Houston in 1985 will be presented here, as follows:

(1) The intercity distance = 225 statute miles. (This distance is assumed to be the same for both airports and vertiports.)

(2) 1965 number of passengers =236,000.

(3) 1985 number of passengers = 6.48 x 236,000 = 1,529,000 (assuming CTOL service only).

(4) Each city is divided into 13 segments as shown in Figure 4. Dallas segment #2 to Houston segment #1 will be used to illustrate the method of calculation by segment pair. 169 such calculations (13 segments x 13 segments) must be made for this city pair. Depending on the size of the other cities, the number of segments varied from five to 21. The radial distance of each ring and the percent of the local origins and destinations of passengers within each ring are shown in Table 5.

Table 5

RADIAL DISTANCE AND PERCENT LOCAL ORIGINS AND DESTINATIONS BY RING

City	Ring	Segment Numbers	Radial Distance (st.mi.)	% Local OD's Within Ring
Dallas	1st	1	2.5	36[a]
	2nd	2,3,4,5	6.3	59[a]
	3rd	6,7,8,9	11.3	84[a]
	4th	10,11,12,13	17.1	100[a]
Houston	1st	1	2.2	46[b]
	2nd	2,3,4,5	5.8	61[b]
	3rd	6,7,8,9	13.3	87[b]
	4th	10,11,12,13	24.7	100[b]

a. From Figure B7.
b. From Figure B6.

(5) For each segment, the percent inhabited is estimated. This is particularly important for cities adjacent to large bodies of water. Dallas segment #2 was estimated to be 90 percent inhabited (Highland Park and White Rock Lake are located in this segment). The other segments (#3, #4, #5) of the second Dallas ring are all estimated to be 100 percent inhabited, as is Houston segment #1.

(6) The number of passengers (assuming CTOL service only) traveling between Dallas #2 and Houston #1 is calculated as follows:

59% -36% = 23% of Dallas OD's lie within the second ring.

Since segment #2 is only 90 percent inhabited,

$\frac{90}{390}$ x 23% = 5.31% of Dallas OD's lie within segment #2

46% of Houston OD's lie within segment #1.

Therefore,

5.31 x .46 = 2.44% of all air travelers travel between Dallas #2 and Houston #1, or

.0244 x 1,529,000 = 37,300 travelers will travel between Dallas #2 and Houston #1.

(7) For each segment, ground times and costs to the nearest airport and vertiport are determined as shown in Table 6.

Table 6

GROUND TIMES AND COSTS

Measure	Dallas #2	Houston #1
CTOL		
Distance to Airport (st.mi.)	5.8	9.7
Through City Traffic?	Yes	Yes
Time to Airport (min.)	35[a]	43[a]
Cost to Airport ($)	2.02[b]	2.64[b]
VTOL		
Distance to Vertiport (st.mi.)	4.4	1.1
Through City Traffic?	Yes	Yes
Time to Vertiport (min.)	33[a]	16[a]
Cost to Vertiport ($)	1.80[b]	1.26[b]

a. Top line, Figure C1.
b. Figure C3.

(8) Air fares and block times are determined as shown in Table 7. A 90-seat fan or jet lift, price = $6 million, is used as the VTOL aircraft.

Table 7

AIR FARES AND BLOCK TIMES

Aircraft Type	Fare ($)	Block Time (hr.)
CTOL	21.73[a]	.79[c]
90-Seat fan or jet lift (price = $6 million)	26.50[b]	.55[c]

a. From Figure 5.
b. From Figure 11.
c. From Figure A7.

(9) Total trip costs between Dallas #2 and Houston #1 are:

CTOL:

$$2.02 + 2.64 + 21.73 = \$26.39$$

VTOL:

$$1.80 + 1.26 + 26.50 = \$29.56$$

(10) Total trip times between Dallas #2 and Houston #1 are:

CTOL:

$$\frac{35}{60} + \frac{43}{60} + .79 = 2.09 \text{ hr.}$$

VTOL:

$$\frac{33}{60} + \frac{16}{60} + .55 = 1.37 \text{ hr.}$$

(11) The cost of saving time by VTOL is:

$$\frac{29.56 - 26.39}{2.09 - 1.37} = \frac{3.17}{.72} = \$4.40/\text{hr.}$$

(12) From Figure 12, 92 percent of air passengers would be willing to pay $4.40 per hour saved. Hence, number of CTOL passengers switching to VTOL would be:

$$.92 \times 37,300 = 34,300.$$

(13) The availability of VTOL service would stimulate the number of VTOL passengers. The percentage increase in the number of passengers due to the additional time saving of VTOL is determined from the following formula:

$$\frac{\Delta P}{P} = kaT^{b}e^{DT/(-c-hT)} \qquad \text{(From Appendix K)}$$

where

a, b, c, e, h, and k are constants,

T = time saved by VTOL over CTOL (in minutes),

D = distance, and

P = number of VTOL passengers before stimulation.

In our example, T = .72 x 60 = 43.2 minutes.

$$\frac{\Delta P}{P} = 115 \times .728 \times (43.2)^{.450}$$

$$\times\ (2.718)^{225 \times 43.2/(-260.9\ -104.4 \times 43.2)} = 59.3.$$

The number of VTOL travelers after stimulation is:

34,300 x (1 + .593) = 54,600.

(14) The number of VTOL passengers for the other 168 Dallas-Houston segment pairs are similarly calculated and added. The total number of VTOL passengers/year for all 169 segment pairs = 1,540,000.

(15) From Figure H1, the VTOL aircraft utilization is 2420 hrs./yr. Hence, each VTOL can make 2420/.55 = 4400 trips per year on this route. At a load factor of .58, each VTOL can carry .58 x 90 x 4400 = 230,000 passengers per year. Hence, number of VTOL aircraft demanded is:

1,540,000 ÷ 230,000 = 6.69.

(16) The number of passengers in each direction per year is 1,540,000 ÷ 2 = 770,000. Assuming uniform scheduling throughout the 365 days of the year, the daily round trip frequency is:

$$\frac{770{,}000}{365 \times .58 \times 90} = 40.5.$$